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## A METHOD FOR MAKING QUANTITATIVE STUDIES OF THE MAIN SPRAY CHARACTERISTICS OF FLYING-BOAT HULL MODELS

By F. W. S. Locke, Jr., and Helen L. Bott
Stevens Institute of Technology

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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ADVANCE RESTRICTED REPORT

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# A METHOD FOR MAKING QUANTITATIVE STUDIES OF THE MAIN SPRAY CHARACTERISTICS OF FLYING-BOAT HULL MODELS

By F. W. S. Locke, Jr. and Helen L. Bott

## SUMMARY

A method and apparatus for making quantitative tests of the spray characteristics of flying-boat-hull models has been developed. Three-view photographs are taken on one negative, with the aid of mirrors; measurements are made from the photographs, and the results are presented in the form of charts which show the side view and the front view of the envelope curves of the principal features of the spray as functions of speed and load. The spray envelopes are located on these charts with reference to the model (not the undisturbed water surface), so that, by superimposing a transparent drawing of a proposed complete flying boat, interferences may be detected at a glance. An example of the latter procedure is shown in figure 5. Here data are given for the lower speed range only, this range being of more importance, in most cases, than the planing range.

The method is applied, in this report, to three related models of flying-boat hulls which differed in one major characteristic of shape; namely, the general overall dead rise. Spray and roach characteristics in smooth water are considered. The models had no tail extensions and were not self-propelled.

From the results obtained, it is concluded that larger dead-rise angles than are ordinarily employed (about 20° at the main step) produce very slightly lower spray blisters in the lower speed range and that smaller dead-rise angles are quite undesirable, especially at high speeds; it is concluded, also, that the roach at the stern (which may interfere with the tail cone at speeds just prior to the hump) becomes lower as the dead rise is increased.

In an appendix a review is made of the problem of scale effect in spray measurements on models. It is concluded that, apart from questions regarding the effect of propeller slipstream, model and flying boat may be expected to have strikingly similar spray under corresponding conditions.

## INTRODUCTION

The spray thrown up by flying-boat hulls during take-off and landing may damage the propellers, the wings, or the tail surfaces. The spray and the stern roach may cause additional resistance, thus hampering take-off.

One of the objects of the work considered in this report was to develop a simple method, together with apparatus, for making quantitative measurements of spray created by a flying-boat-hull model while moving on the water.

Another objective of the work was to develop a form of presentation of results which would give the designer a quick, vivid picture, and permit ready comparison between hull forms. The form of presentation adopted involves plots of the results on outline side and front views of the model, as shown in figure 5. The XPB2M-1 flying boat has been drawn in on this chart to illustrate how interferences with parts of the airplane can be brought out. A designer can easily prepare a similar drawing of any proposed design on transparent paper and, by laying the transparent sheet over the appropriate chart of test results, determine directly the space relations between parts of the proposed airplane and the spray when the hull in question is used. It should be noted that, while the tests herein reported were made without tail cones, the tail cone can easily be incorporated in the model if desired.

This investigation, conducted at the Stevens Institute of Technology, was sponsored by, and conducted with financial assistance from, the National Advisory Committee for Aeronautics.

## METHOD FOR RECORDING SPRAY

The subject of spray characteristics has received considerable attention in the past, but most of the previous work appears to have been essentially qualitative in character.

Sottorf (reference 1) used a method of measuring the height and contour of the spray in one plane relative to the still water by means of "measuring needles." His method was discarded for present use as being too time-consuming and not giving sufficiently complete information. Careful thought was given to several other methods of measuring the spray and it was finally decided that photographic methods offered the greatest possibilities for obtaining accurate results quickly.

Satisfactory photographs of flying-boat models require very short exposures to stop the motion. Dr. Harold E. Edgerton of the Massachusetts Institute of Technology has developed several types of light suitable for the purpose. One type, adapted to single shots, is marketed under the trade name Kodatron. It gives a flash time of somewhat less than 0.0002 second. Operating on the principle of the rapid discharge of a condenser, time (normally 10 sec or more) is required to charge the condenser after each discharge. Another type of light is designed to give a continuous series of rapid flashes. Operating on ordinary alternating current, it flashes sixty times a second, the period of each flash being about 0.00005 second. When used with a motion-picture camera, the camera shutter is removed and the film fed through at a constant speed so that 60 photographs per second are recorded.

Where performance in still water gives sufficiently complete information, a single photograph of large size is obviously better than a series of photographs which, for reasons of convenience in presentation, must necessarily be smaller. One photograph will show as much as a series because the spray and wave patterns are of uniform pattern once the hull has been brought up to steady speed. Where knowledge of performance in rough water is necessary, a series of photographs is preferable because the spray and wave patterns change with the relative positions of the hull and waves.

The forebody of a flying-boat hull causes at least two, more or less distinct, types of spray. These are illustrated in the sketches in figure 6. The first type grows out of the bow wave at very low speeds and builds up in the form of a blister of increasing height, with its peak progressively farther aft, as the speed advances toward the planing range. Although influenced to some extent by rough water, this type of spray may be considered to be primarily a smooth-water characteristic, and studied as such. The second type of forebody spray is primarily a rough-water characteristic and is attributable to impact with head seas of the relatively blunt form of the bow itself; it can be particularly objectionable in obscuring vision through the windshield.

A third type of spray is produced by the afterbody of a flying-boat hull. The afterbody, in combination with the wake of the forebody, causes a roach (or "rooster's tail") which follows the hull behind the stern post, and often reaches a considerable height at speeds within a narrow range near the hump; it is largely uninfluenced by rough water.

This report is concerned with the first type of forebody spray and with the roach. Hence, the tests could be made in still water and the single photograph method could be used.

Another factor to be considered, apart from the question of smooth or rough water (single photograph against motion-picture record), was the number of dimensions in which spray form should be studied. For the roach, which is essentially two-dimensional, a side view tells the whole story. For the blister, side, front, and plan views are all of value, and a method and apparatus has been developed by which all three views may be taken simultaneously by one camera and appear on the same negative.

A schematic sketch on figure 1 and the photograph on figure 2 show the general layout of the photographic arrangements. Two high-speed Edgerton Kodatron lights, connected in parallel, are used for illumination. The camera is mounted on the ceiling above the tank and takes a direct top view of the model. Two large mirrors are arranged so that the camera sees a front view of the model in one mirror and a side view in the other. The electrical circuit for the lights is completed by a switch actuated by the towing carriage.

The height of the peak of the spray blister above the forebody keel and its longitudinal location, with respect to the main step, can be read directly from the side view with the aid of a grid painted on the side of the model; foreshortening is small in this view and can be neglected. The lateral location of the peak of the blister can be obtained from the front view with the aid of a separate photograph of a calibration grid. Because of the foreshortening in the front view, a series of photographs has been prepared for various longitudinal positions of the calibration grid with respect to the position in which the model is photographed; the particular grid photograph is then selected for which the grid position most nearly coincides with the longitudinal location of the blister peak, as already determined from the side view. The accuracy of the procedure as a whole can be judged by the scatter of the test points on the various charts of test results.

The tests reported herein were carried out in greater detail than is considered necessary for future work. This was done to provide a broad background at the start. On the basis of this background, it is believed that about half as many tests

will be sufficient in further work - the reduction being effected mainly by omitting speeds, particularly in the planing range, which is of less interest. The testing time thus saved will not be great, but the saving in analysis time will be considerable.

## APPLICATION OF METHOD TO A STUDY OF EFFECT OF DEAD RISE

Quantitative data are presented on the forebody spray and on the stern reach for three related models incorporating systematic changes in the general, over-all hull dead rise. In previous tests of the same models for resistance and porpoising characteristics, reported in reference 2, substantial qualitative differences in the spray characteristics had appeared to exist; these models were therefore chosen as being of interest in themselves, besides being appropriate models to use in a first trial of the newly-developed method of measuring spray. Data were obtained for ranges of speed and load considered likely to occur in practice.

Spray is ordinarily of more importance at speeds in the lower range than at planing speeds. For the lower speed range, because the longitudinal center of gravity is usually fixed within relatively narrow limits by considerations of trim in the planing range, it is practicable for most purposes to reduce the data to a single chart representing free-to-trim tests with a single, appropriate center of gravity position (as on fig. 5 for the 20° dead-rise model). Such a chart will show, in convenient form for reference, most of the data needed - covering variations of speed and load - for a given hull form.

The planing-range data are less readily combined on a single chart because trim angle has to be considered as an extra variable. But, since they are ordinarily of less importance than the lower-speed data, this is considered of small consequence and no attempt to combine them has been made in this report. The lesser importance of spray in the planing range is due mainly to the fact that the preponderance of the spray in this range is of very low mass, appearing largely as a mist. The high, solid sheets of spray, characteristic of the lower speeds, degenerate at planing speeds to less solid sheets of much lower height, which are, in general, well clear of all parts of the airplane.

The results of the present tests indicate much smaller differences between the spray characteristics of the three models,

in the lower speed range, than were anticipated. This is attributable, not to discrepancies between the earlier qualitative indications and the quantitative measurements, but mainly to the fact that the quantitative measurements relate the spray dimensions to the hull, whereas visual observation tends to relate them to the undisturbed water surface. This is an important distinction; in order to decide upon questions of interference between the spray and various parts of the airplane, spray dimensions should obviously be relative to the hull.

## Models

The parent model of the series (Stevens Model No. 439-01) was basically a 1/30-scale model of the XPB2M-1, with a 20° dead-rise angle at the main step. The other two (Models Nos. 439-02 and 439-03) had, respectively, 50 and 150 percent of the dead rise of the parent at each cross section. All three models differed from the models ordinarily used at this Tank in that the sides above the chines were vertical and extended to a much greater height and that the tail cone was omitted. A grid was painted on the starboard side to facilitate analysis of the photographs. Particulars are given on page 17, and the lines of the models are on figures 3 and 4.

## Setup

The model was towed by a simple apparatus which permitted freedom in heave and (when desired) trim, and provided restraint in heel and yaw.

## Test Procedure

All the tests were made at constant speeds and in substantially still water. The tests of each model followed the same basic program. In detail:

1. Tests were made at each of a number of fixed speeds covering the range up to get-away and spaced so as to get a comprehensive picture of the spray characteristics.

2. Tests at the lower speeds, up to and including the hump, were run free-to-trim; at higher speeds, in the planing range, a number of fixed trims were used.

3. Values of the load coefficient were chosen to cover ranges of values likely to be found in practice at the various speeds.

4. At each test condition, a three-view photograph was taken of the model under way. Samples are given on figures 7 to 10.

It was originally planned to obtain the roach measurements from the three-view photograph, but when this proved inconvenient, special supplementary side-view photographs were taken of the roach. These covered the same ranges of loads but narrower ranges of speeds.

## Discussion of Results

Low-speed, free-to-trim tests. - The results of the tests at low speeds, free-to-trim, are shown for the three models on figures 11 to 13. These charts, one for each model, show the location of the peak of the blister, as measured from the photographs, together with envelope curves for variations of $C_V$. The actual measurements are shown by points; there is some scatter, but a straight line is seen to fit reasonably well the points for each value of $C_\Delta$. A cross section of the blister, at $C_\Delta = 0.80$ and at the value of $C_V$ (namely, 2.27), which puts the peak near the longitudinal position of the main step, is shown in each view. These cross sections are not intended to be especially accurate, but rather to be illustrative of the general extent of the blister.

Figures 14 to 16 combine the curves for the three different models, each figure covering one value of $C_\Delta$. From these charts it is clear that, in the low-speed region, increasing the dead rise lowers the blister height relative to the hull, but by only very little.

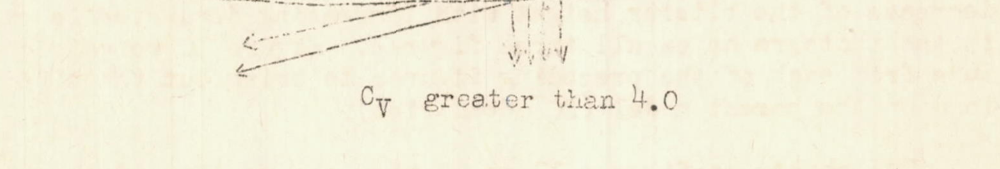
Selected photographs are shown on figures 7 to 9; each sheet shows the three models at one value of $C_\Delta$ and at the same value of $C_V$ (2.27) used for showing the cross sections of the blisters on the charts previously described. It will be noted that a slight decrease of the blister height with increasing dead rise is evident in the photographs on all three figures. Figure 10 repeats one picture from each of the preceding figures to bring out the effect of load on the parent model (20° dead rise).

The charts on figures 17 to 19 show the results of the supplementary tests to determine the profile of the roach. These charts are

to the same scale as the other charts in this report and are therefore directly comparable. They indicate that the roach is of critical importance only in a very short speed range, $C_V$ about 2.4 to 2.8. Envelope curves have been drawn and these are summarized in the chart on figure 20. It will be seen that the model with 30° dead rise has by far the lowest roach at all three values of the load coefficient covered by the tests. The roach may easily strike the tail cone, thereby causing substantial increases of resistance in the narrow speed range, near the hump, where the roach is greatest.

High-speed, fixed-trim tests. - In the high-speed region, tests were run at various values of fixed trim. This region was not as exhaustively studied as the low-speed region because it appeared to be of less interest. As the speed increases, the blister moves farther aft, as may be seen on figures 25 to 33, and at the light loads, ordinarily occurring in the planing range, the spray does not often become serious.

There are essentially two parts to the spray at high speeds, which are clearly seen in the photographs in figures 21 to 23. One part is the remnant into which the characteristic domelike blister has degenerated. This appears as a long, low, narrow ridge, almost parallel to the hull. The other part, which was present in rudimentary form at lower speeds, shoots out laterally from the region of the pressure area on the forebody. The following sketch shows the two parts.




$C_V$ greater than 4.0

The lateral spray appears to be very dependent on the amount of dead rise. With 10° dead rise at the step, the amount of spray coming off laterally is tremendous, and increases with trim and load; it would seem almost certain to cause damage to any part of the airplane which it struck. As the dead rise increases, the height and volume of this spray diminishes rapidly. The remnant of the blister at high speeds does not appear to have very much importance, though it might occasionally cause trouble on flying boats having twin rudders placed low down.

On all three models a tremendously confused, messy wake appeared in the planing range when the trim angle was high enough for the afterbody bottom to be wetted. This wake usually followed up the afterbody sides and would have continued out along the tail cone if one had been present (as evidenced by other experience), thereby causing important increases of resistance.

General discussion. - The need for quantitative spray measurements on proposed designs is brought out quite forcibly by the results here presented. These results show, for instance, that dead rise does not have a very important influence on the height of the spray at low speeds when measured with respect to the hull. Yet there have been various comments, originating at this Tank as well as elsewhere (references 2, 3, and 4), to the effect that increased dead rise reduces the spray height. These comments are probably to be attributed to the tendency, previously suggested, for the eye to refer spray heights to the surrounding still-water surface rather than to the model. With increased dead rise the spray is lower relative to the water surface, but the model sinks deeper into the water so that the net effect, relative to the form, is small.

The chart on figure 5 shows the free-to-trim results obtained on the model with 20° dead rise, for the low-speed range where the spray characteristics are of most importance. The bottom of this model, up to and including the chines, is the same as the bottom of the XPB2M-1 hull. The main features of the XPB2M-1 flying boat have been drawn in on this chart, as previously mentioned. The inboard flap is shown deflected to 30° - its normal position during take-off. It will be noted that for $C_V = 2.5$, when $C_\Delta$ would be about 0.80 with the normal gross load of the flying boat, the spray clears the flap. However, as discussed at greater length in the appendix, special tests of a model of the XPB2M-1, and experience with the actual flying boat, showed that comparatively large amounts of spray struck the flap on the low side when a heel angle of the order of 3° was introduced. The present report does not cover the effects of heel angle; the XPB2M-1 case merely brings

out the need for further work in which it is considered. The chart shows that, with normal loading, the propellers are well clear of the spray; the roach, however, wets the tail cone and undoubtedly causes increased resistance for a short range of speeds.

It is believed that the method of spray measurement described in this report has several advantages. It allows reasonably accurate measurement of the spray characteristics. At the same time, the tests may be run off quite quickly (as many as 90 photographs have been taken by this method in 3 hr). It is not necessary even that the photographs be analyzed if a designer is in a hurry for an answer. With tests of two models under otherwise identical conditions, a photographic negative for one model can be laid on a photographic positive for the other and direct comparison made. It is believed that the method can be used to advance a general knowledge of spray and roach characteristics and thereby contribute to improvement of hull designs.

Further basic work appears necessary to clarify the effects on the spray characteristics of running propellers and of heel angle.

## CONCLUSIONS

1. A simple and rapid means has been developed for making quantitative spray tests on models of flying-boat hulls.

2. On the basis of results obtained on three models, it is concluded regarding the effect of dead rise, that:

(a) Spray is, in general, of more importance at lower speeds than at planing speeds.

(b) At the lower speeds, up to and including the hump, the hull dead rise does not have a very pronounced effect on the height of the spray, when this is measured relative to the hull, though increasing the dead rise lowers the spray very slightly. Greater load increases the spray height very rapidly on all three of the models investigated.

(c) At speeds just prior to the hump, the roach at the stern is dependent, to a marked degree, on the dead rise. Increasing the dead rise lowers the height of the roach. Greater load increases the height of this roach.

(d) At planing speeds the remnants of the blister are not very important. The spray that is thrown out laterally is very high at low dead-rise angles. Its height increases as trim angle and load are increased - singly or in combination.

3. From the discussion in the appendix, it is concluded that, with nearly all reasonably conventional models, no true scale effect on spray need be expected.

Stevens Institute of Technology,
Hoboken, N. J., July 28, 1943.

APPENDIX

GENERAL NOTES ON SCALE EFFECT IN SPRAY TESTS

The question of scale effect on spray formation arises from time to time. (See, for instance, reference 5.) The thought appears to be that surface tension, or something of that sort, which is unimportant in flying-boat size, becomes of sufficient importance in model size to influence the spray pattern, even though it does not appreciably affect true gravity waves. Certain well-known experiments of Sottorf on a particular series of models of differing size (reference 6) are sometimes quoted in support of this view. But Sottorf's experience does not seem to have been borne out generally, and may possibly be an isolated case.

To the casual observer there are large apparent differences between the spray blister on a flying boat and that on a model. These differences are certainly attributable in large part to the fact that the spray blister on a model ordinarily has a distinctly "glassy" appearance, while on a flying boat it is split up into myriads of droplets. However, under the right conditions, glassy blisters will sometimes form at full-scale, while, on the other hand, the model blister can be broken up by reducing the surface

tension. Experiments on models have been made at this Tank, for instance, in which the surface tension of the water was reduced in the ratio of about 1:3 by the addition of a "wetting agent". The result was to break up the blister into fine spray; the envelope shape was, however, practically unchanged, and its height and location unaltered.

Coombes, in references 7 and 8, states that, with sharp chines, flying boat and model may be expected to give very similar results. He goes on to say that "With rounded chines, the flow on the small model breaks away, but that on the large one follows round the chines . . . ." This can hardly be due to surface tension since the smaller model has proportionately larger surface tension forces, and the statement is in direct opposition to the usual criticism that the "flow" (presumably Coombes is referring to a thin sheet) on a smaller model tends to follow a convex surface more readily than on a large model. But the fact is, in any case, that most forms have sharp chines.

Mitchell (reference 9) adds to the confusion, in discussing the behavior of 1/8- and 1/12-scale models, when he states that the smaller "model also appeared much dirtier than the larger one."

Richardson (reference 10) tells of one instance in which moving pictures of the waves created by models were compared with moving pictures of the waves created by full-size flying boats, the comparison showing remarkable agreement. In another instance, a new model, based on an old one but to a different scale, appeared to give more spray than the original; on retesting both on the same occasion, however, the conditions were found to be substantially identical. Further, photographs showed the full size to be in good agreement with the models.

Early full-scale flight tests of the XPB2M-1 showed that, at moderate speeds during take-off, large quantities of heavy spray occasionally struck one of the wing flaps with sufficient force to cause damage. It appeared that the damage occurred on the low side while the airplane was heeled far enough to put the low wing-tip float onto the water. Model experiments were undertaken at this Tank to investigate this matter. A wire frame representing the outline of the flap was fitted to a 1/30-scale model (having the same beam as the models considered in this report). It was found that with no heel angle the spray blister just missed the "flap," and this was borne out by moving pictures of a 1/12-scale model tested by the NACA (likewise without self-propulsion). However, when the 1/30-scale model was given the same heel angle as

the full-size airplane, the spray blister passed through the wire representation of the flap. Alterations to the model succeeded in correcting the trouble, and the same alteration was applied successfully to the actual flying boat. This is the most satisfactory confirmation of similarity in the spray formations on model and flying boat within the experience of this Tank, and it should be especially noted that it was obtained with a model which was not self-propelled.

Self-propelled-model tests of a twin-engine flying boat have been reported by the NACA in reference 11, where it is stated that ". . . the slipstream greatly increases the height and the volume of undesirable spray at taxying speeds. The slipstream reduces the height and amount of water striking the tail surfaces at high speeds." It is not very clear whether the running propellers had any strong influence on the relatively heavy spray blister as such, or whether their effect was limited to the reasonably light spray ordinarily found in the air near a blister. The statement regarding slipstream effect at high speeds (that it reduces "the height and amount of water striking the tail surfaces"), can hardly be intended to apply to anything other than the light spray found near the afterbody at high speeds when self-propulsion is not employed.

If the propellers were to get into the relatively heavy spray blister at taxying speeds, it seems almost inevitable that they would suffer serious damage. On the other hand, it is not surprising that they pick up a large amount of light, loose spray and fling it back over the wing. It would appear possible that the slipstream might lower the height of the blister aft of the plane of the propeller disk, because of the relatively higher air velocities existing there. The experience with the XPB2M-1 described previously appears to indicate, however, that the slipstream aft of the plane of rotation may not have any appreciable influence on the heavier water in the true blister.

It is not thought that the region ahead of the plane of rotation could be very strongly influenced because of the relatively low air velocities in this region. It is known, of course, that idling propellers on landplanes will pick up spray from a puddle directly underneath the propeller and that the propeller will sometimes, when rotating at somewhat higher speed, condense spray out of the atmosphere. The actual mass of water involved in both of these cases is, however, very small. It is suggested therefore that, in most instances where the propeller picks up spray, very low masses of water are involved - which may pit the propeller blades but scarcely cause structural damage to the airplane.

Systematic, quantitative experiments with a self-propelled model would be of considerable aid in clearing up the influence of propellers on the spray characteristics. Until further evidence is available on this point, however, it is believed that, in most reasonably conventional cases, the spray blisters on flying boat and model can be expected to be strikingly similar under corresponding conditions.

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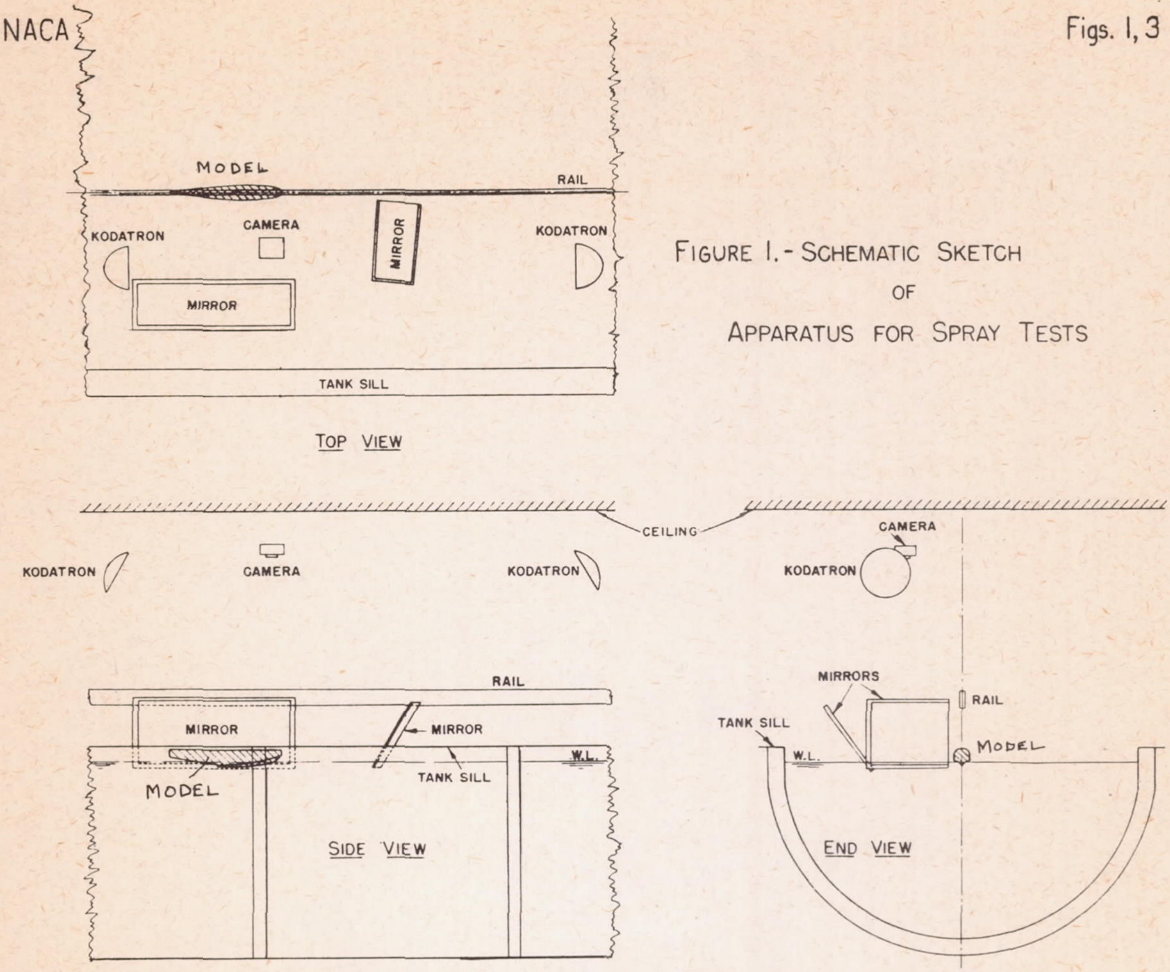


FIGURE 1.- SCHEMATIC SKETCH OF APPARATUS FOR SPRAY TESTS

CORRESPONDING MODELS IN REPORT NO. 183 (SEE REFERENCE 2) ARE NUMBERED AS FOLLOWS:
10°DEADRISE, NO. 400-1; 20°DEADRISE, NO. 339-1; 30°DEADRISE, NO. 401-1.

| | | | |
|---|---|---|---|
| MODEL NO. | 439-2 | 439-1 | 439-3 |
| BEAM AT MAIN STEP, IN. | 5.40 | 5.40 | 5.40 |
| DEADRISE AT MAIN STEP, DEG | 10.0 | 20.0 | 30.0 |
| STEP HEIGHT, IN. | 0.27 | 0.27 | 0.27 |
| ANGLE BETWEEN FORE- AND AFTERBODY KEELS, DEG | 7.0 | 7.0 | 7.0 |
| AFTERBODY LENGTH, IN. | 14.85 | 14.85 | 14.85 |
| C.G. FORWARD OF MAIN STEP, IN. | 2.33 | 2.33 | 2.33 |
| C.G. ABOVE B.L., IN. | 4.89 | 4.89 | 4.89 |
| ANGLE BETWEEN FOREBODY KEEL AND B.L., DEG | 2.0 | 2.0 | 2.0 |

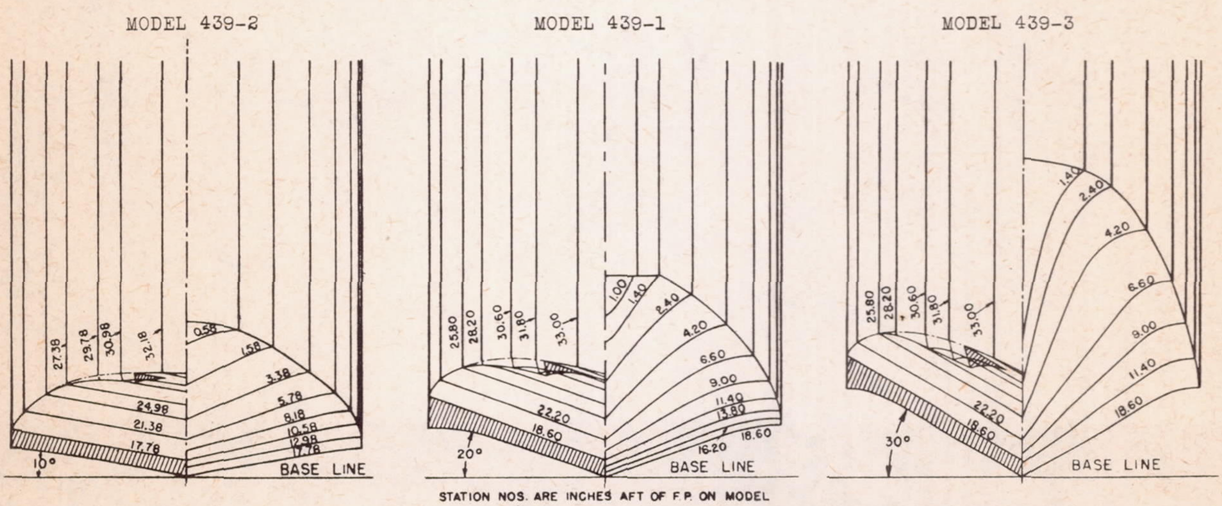


FIGURE 3. BODY PLANS OF MODELS

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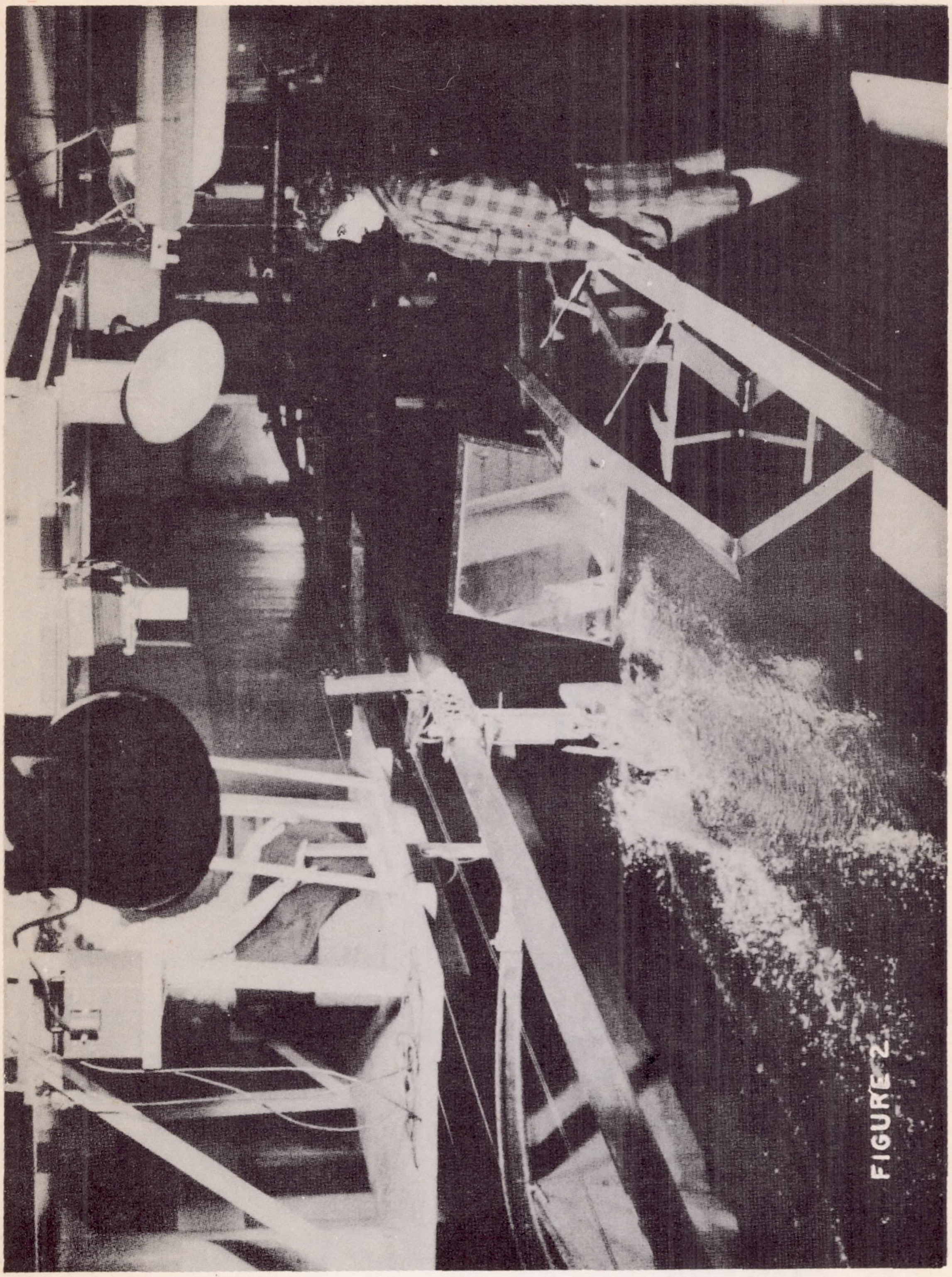


Figure 2

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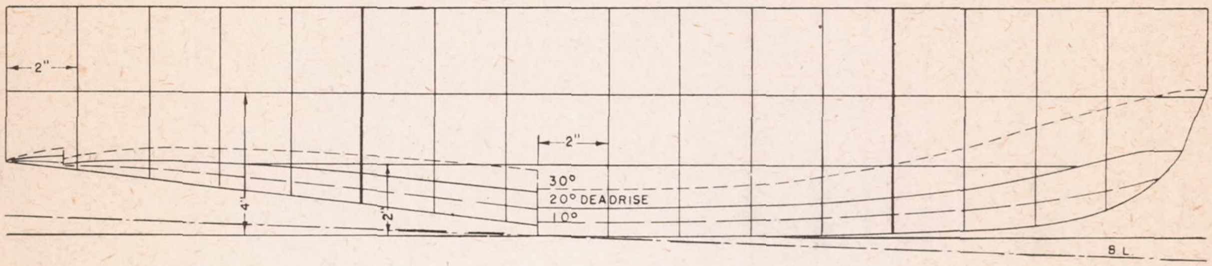
FIGURE 4.- PROFILE DRAWING OF HULLS SHOWING LOCATION OF GRID PAINTED ON STARBOARD SIDE




THE BODY PLANS IN FIGURE 3 ARE DRAWN WITH RESPECT TO THE BASELINE HERE INDICATED

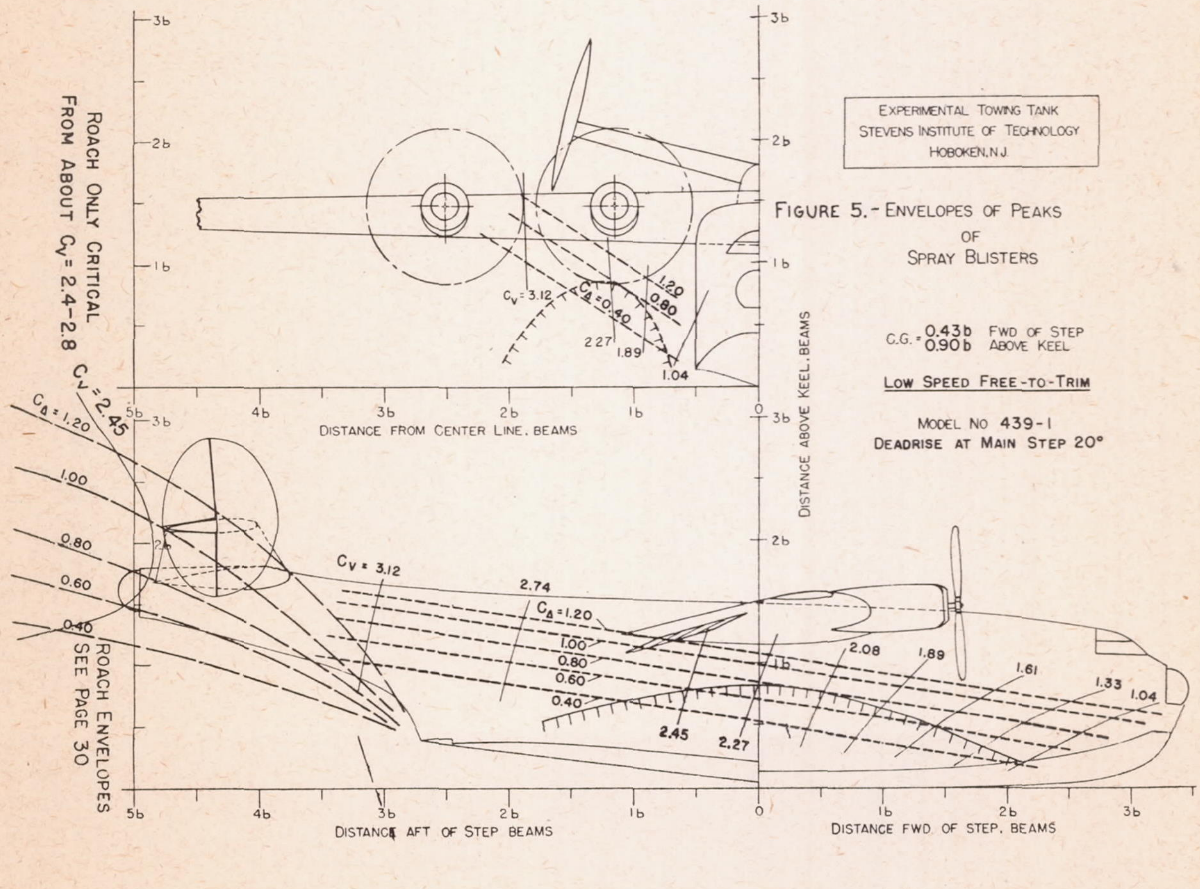



FIGURE 5.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

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## INDEX OF CHARTS AND PHOTOGRAPHS

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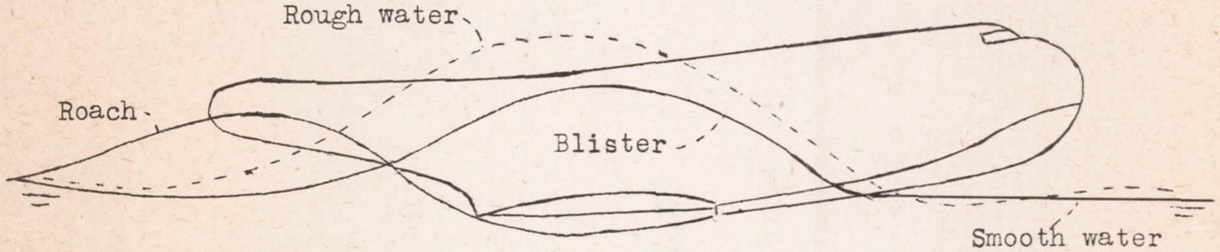
$C_v$ = approximately 1.0




$C_v$ = approximately 2.5

The hump occurs at $C_v$ = approximately 2.8

Figure 6

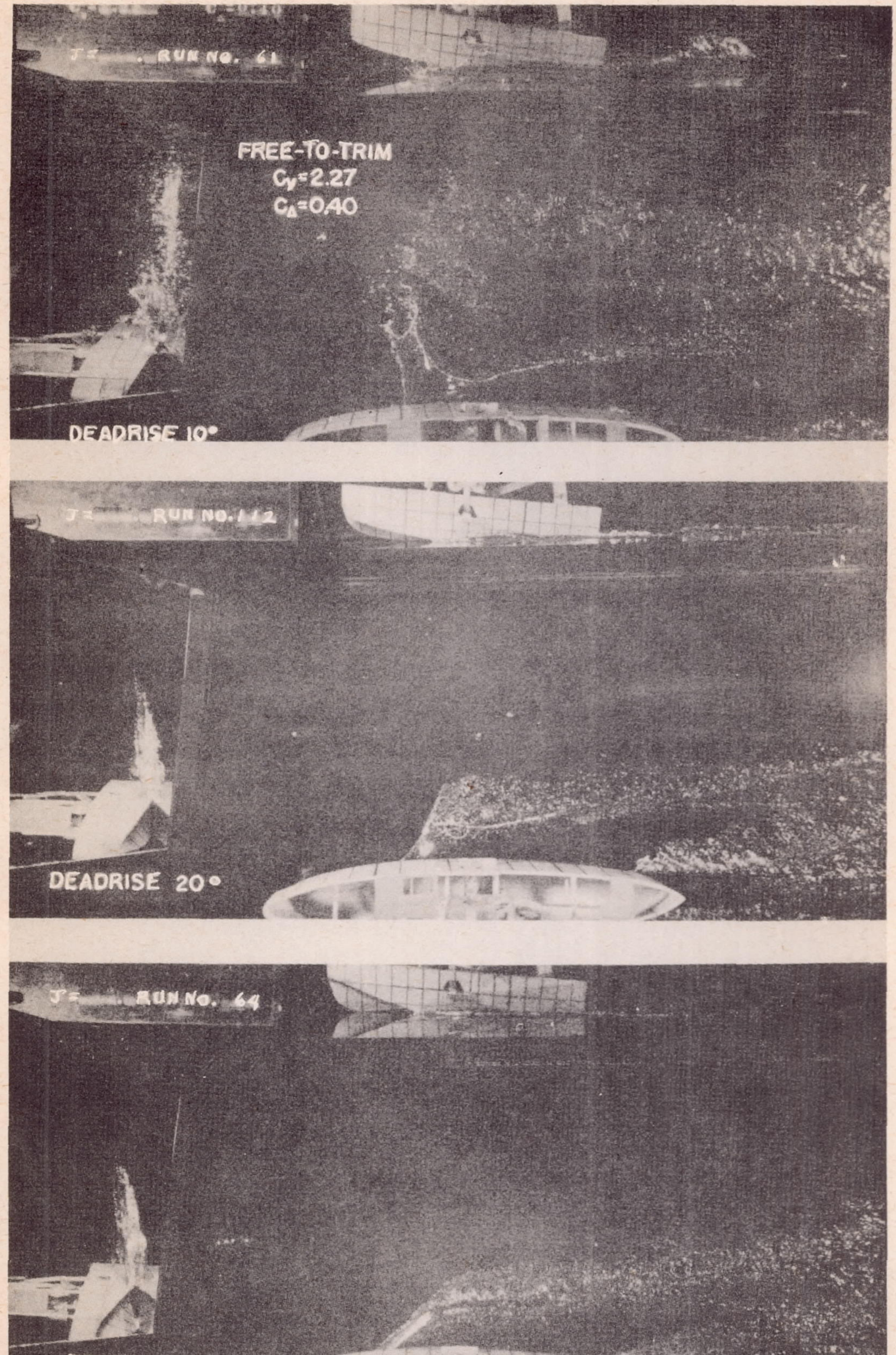

RUN NO. 61
FREE-TO-TRIM
$C_V$=2.27
$C_\Delta$=0.40
DEADRISE 10°
RUN NO. 112
DEADRISE 20°
RUN NO. 64
DEADRISE 30°

Figure 7

W-69

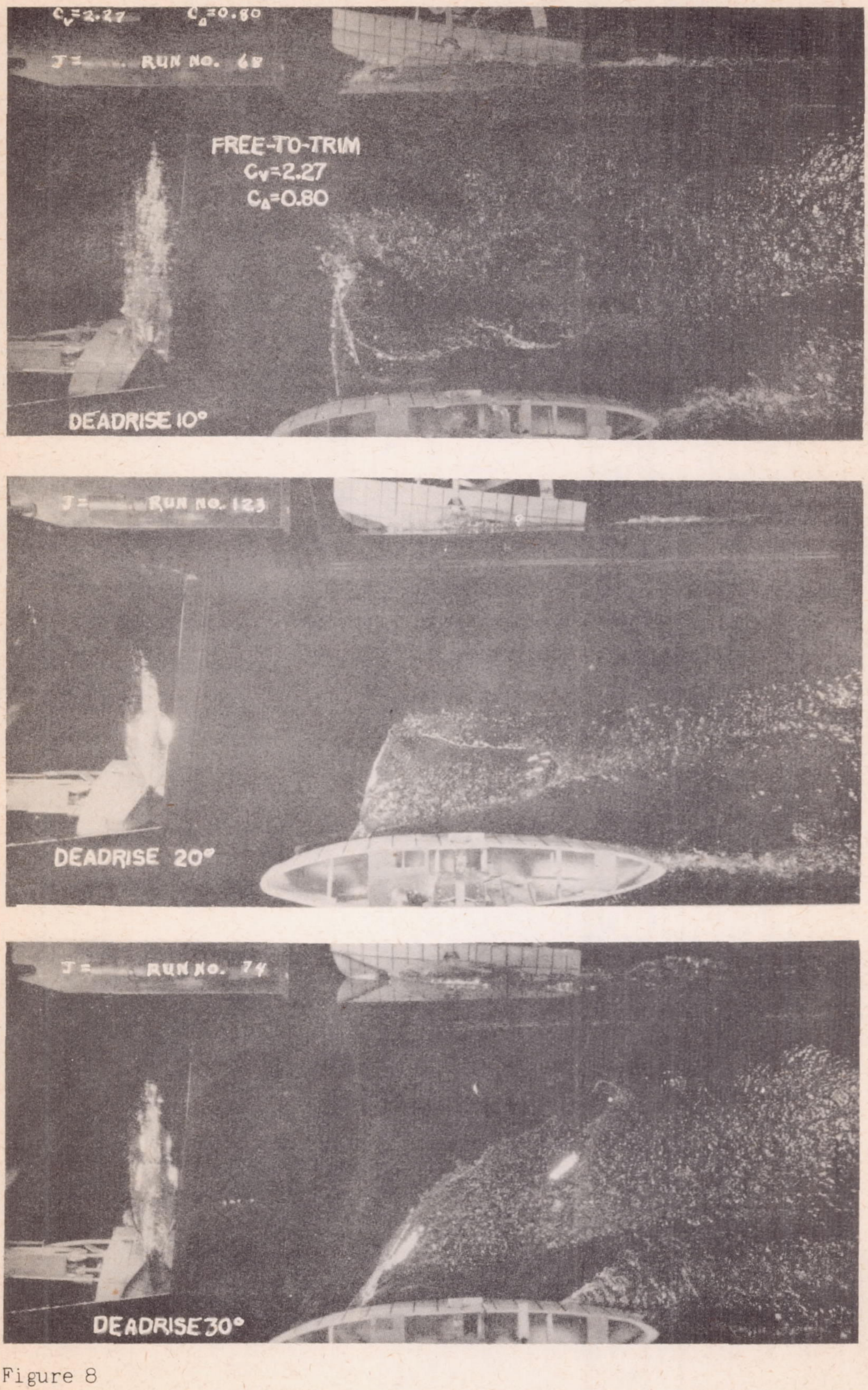

RUN NO. 68
FREE-TO-TRIM
$C_V$=2.27
$C_\Delta$=0.80
DEADRISE 10°
RUN NO. 123
DEADRISE 20°
RUN NO. 74
DEADRISE 30°

Figure 8

W-69

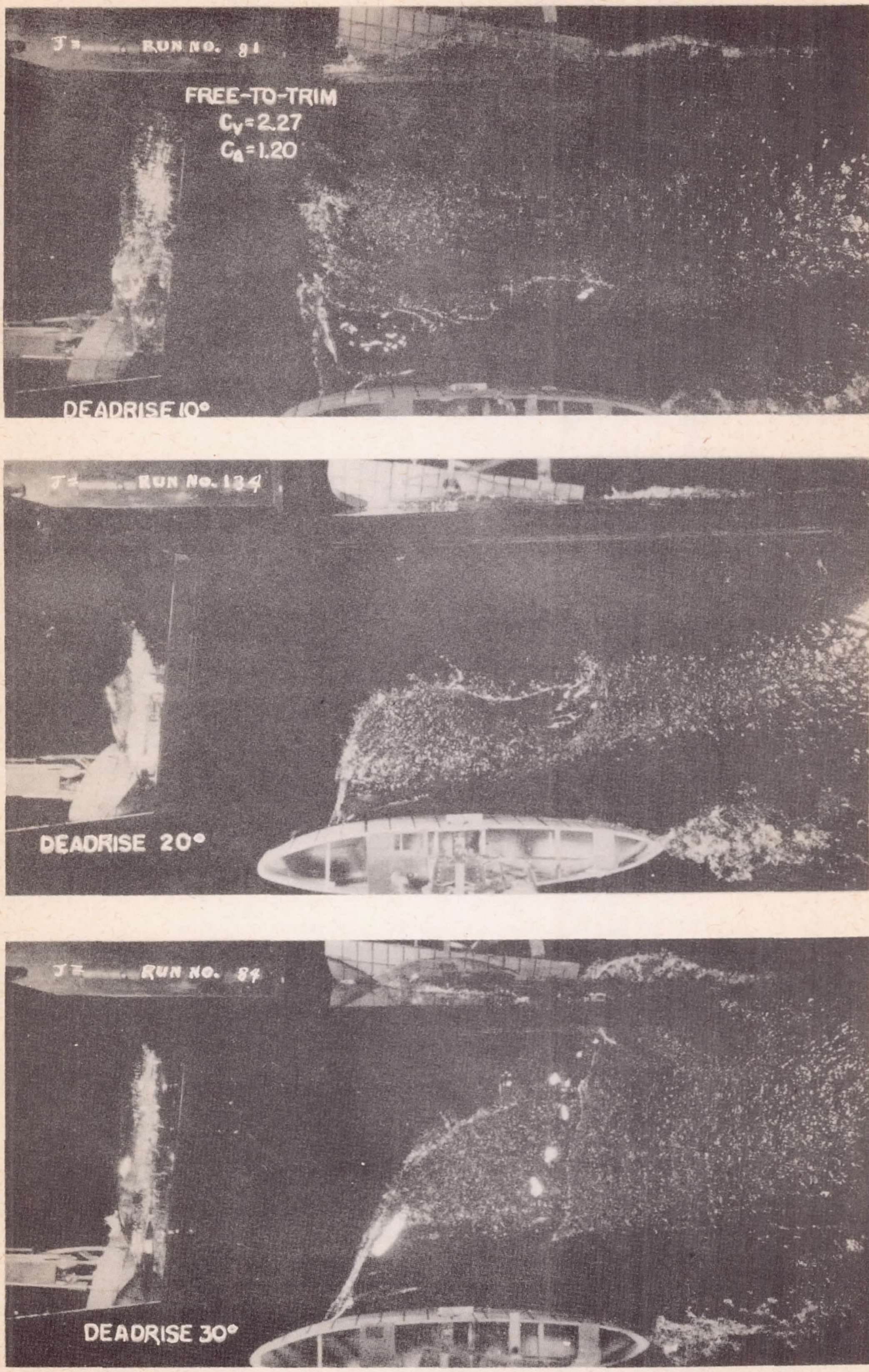

RUN NO. 91
FREE-TO-TRIM
$C_V$=2.27
$C_\Delta$=1.20
DEADRISE 10°
RUN NO. 134
DEADRISE 20°
RUN NO. 84
DEADRISE 30°

Figure 9

W-69

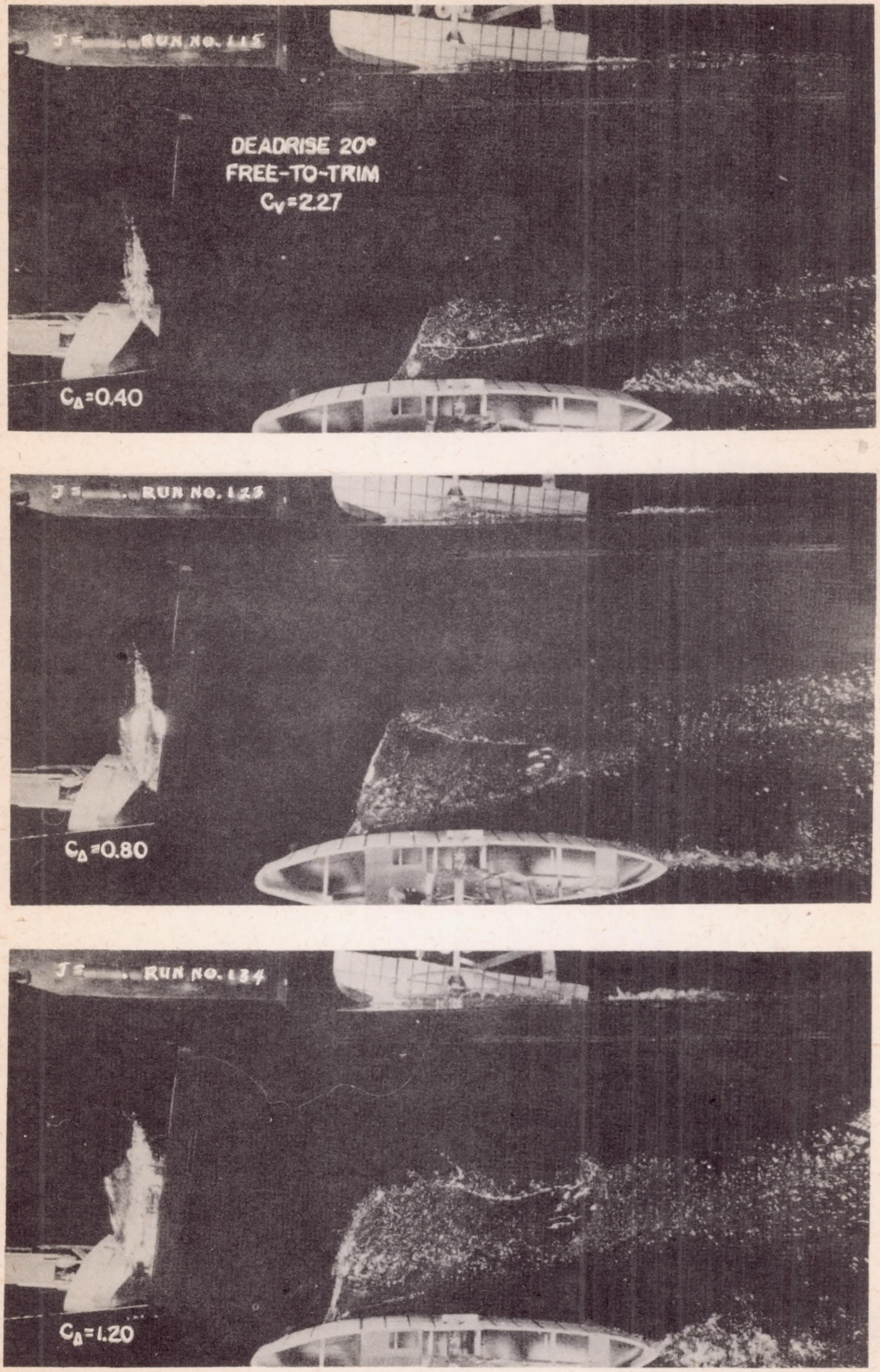



Figure 10

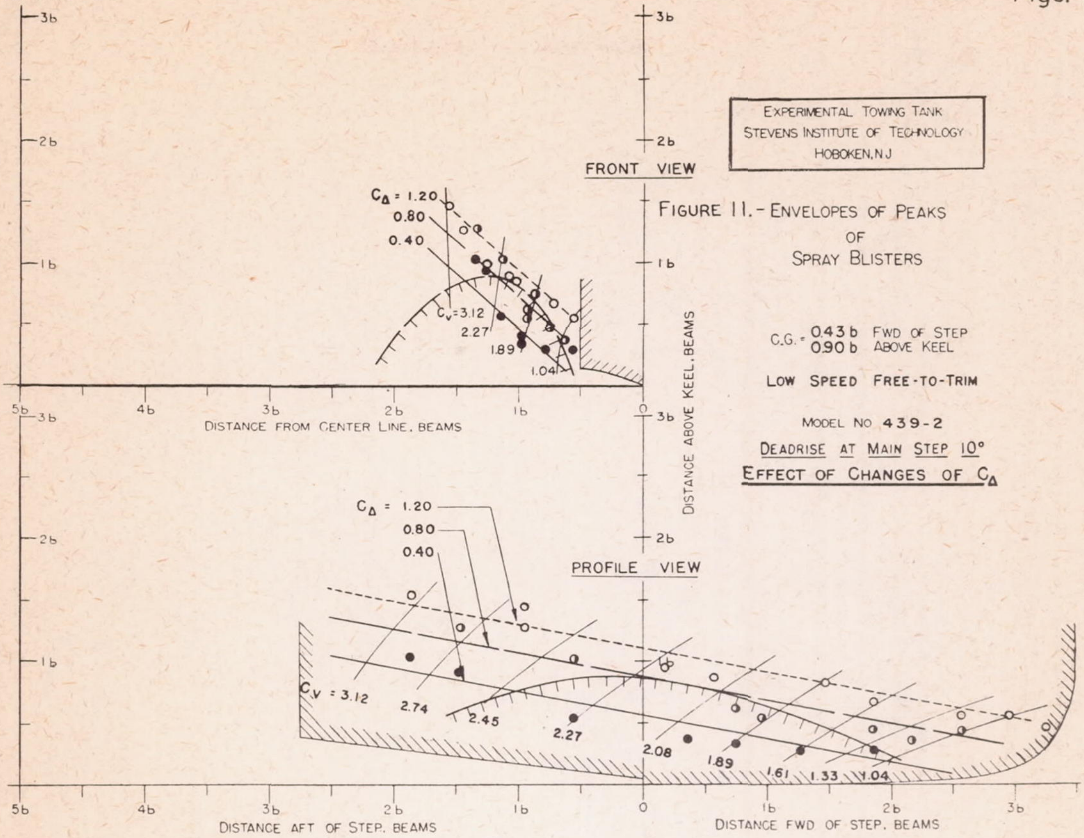



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FIGURE 11.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

C.G. = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

LOW SPEED FREE-TO-TRIM

MODEL NO 439-2

DEADRISE AT MAIN STEP 10°

EFFECT OF CHANGES OF $C_\Delta$

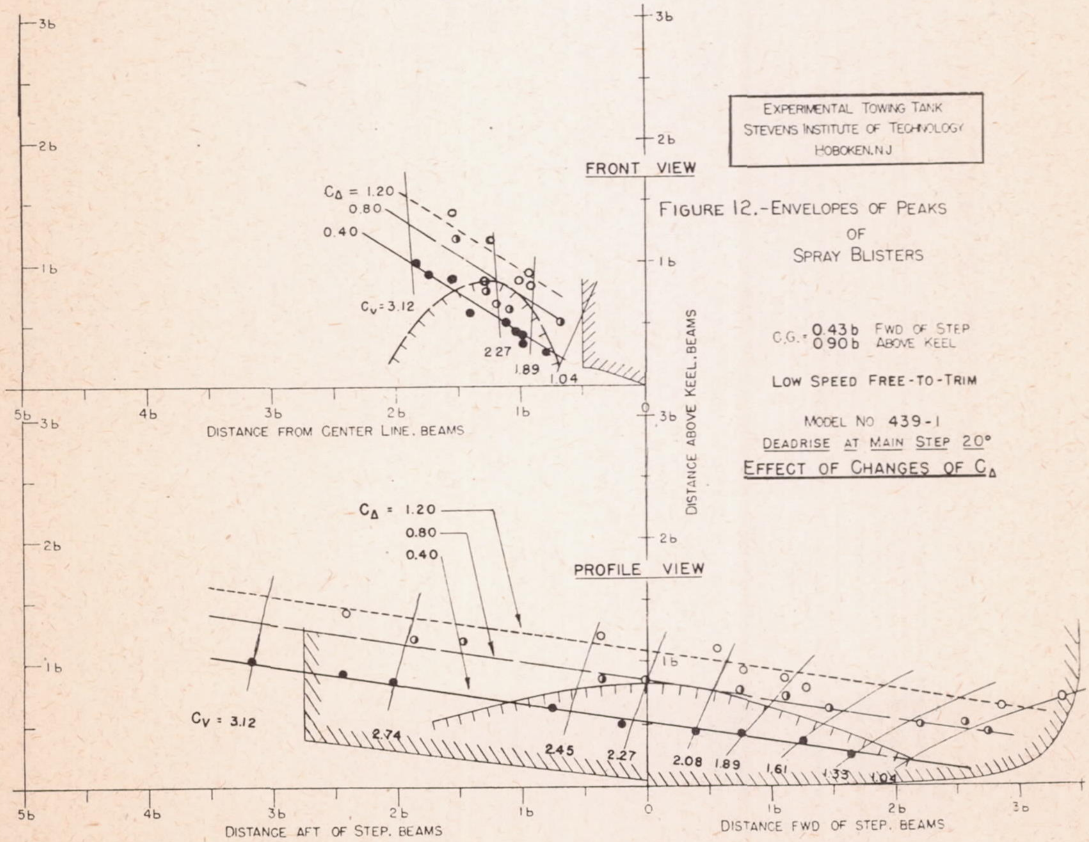


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FIGURE 12.-ENVELOPES OF PEAKS OF SPRAY BLISTERS

C.G. = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

LOW SPEED FREE-TO-TRIM

MODEL NO 439-1

DEADRISE AT MAIN STEP 20°

EFFECT OF CHANGES OF $C_\Delta$

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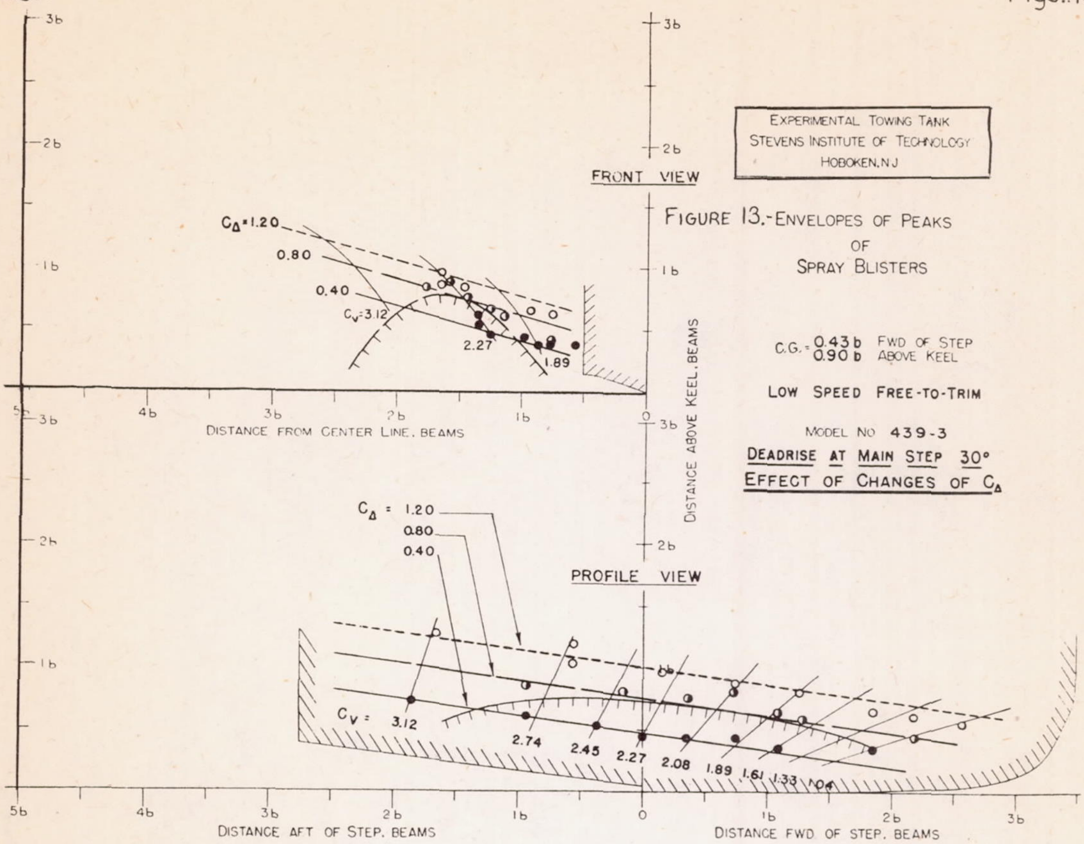


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FIGURE 13.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

C.G. = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

LOW SPEED FREE-TO-TRIM

MODEL NO 439-3

DEADRISE AT MAIN STEP 30°

EFFECT OF CHANGES OF $C_\Delta$

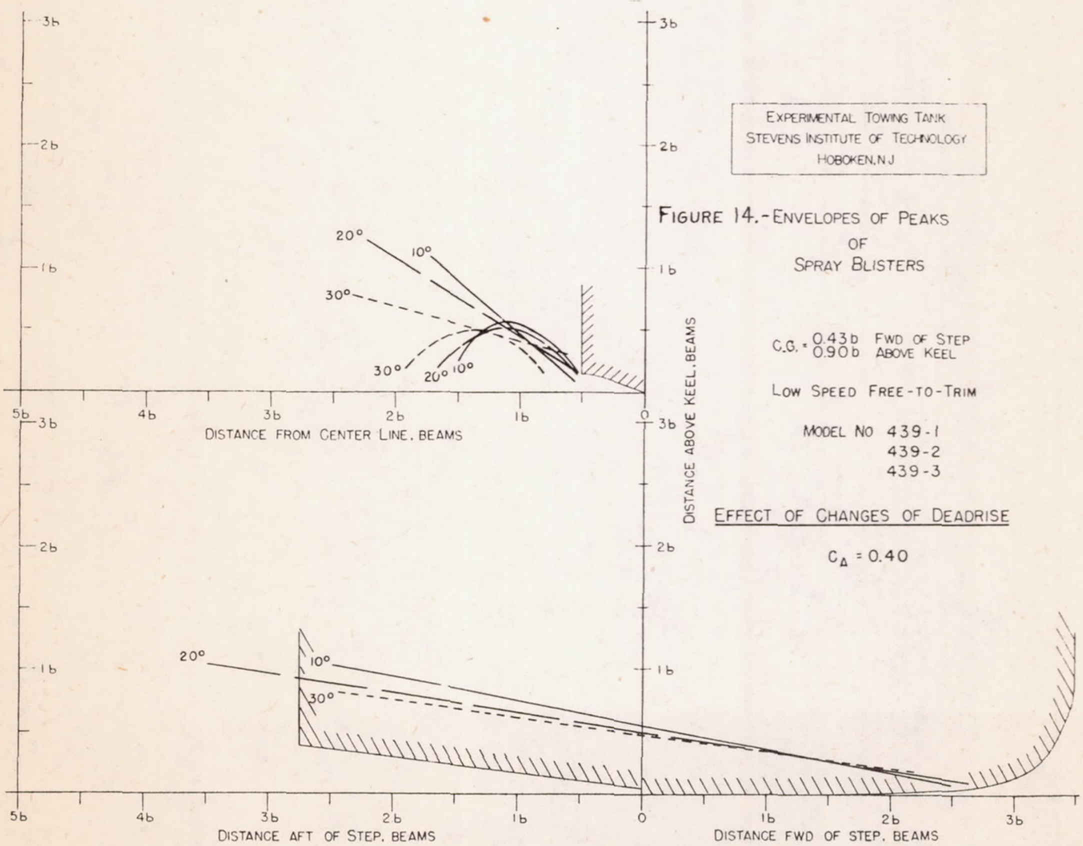


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FIGURE 14.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

C.G. = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

LOW SPEED FREE-TO-TRIM

MODEL NO 439-1
439-2
439-3

EFFECT OF CHANGES OF DEADRISE

$C_\Delta$ = 0.40

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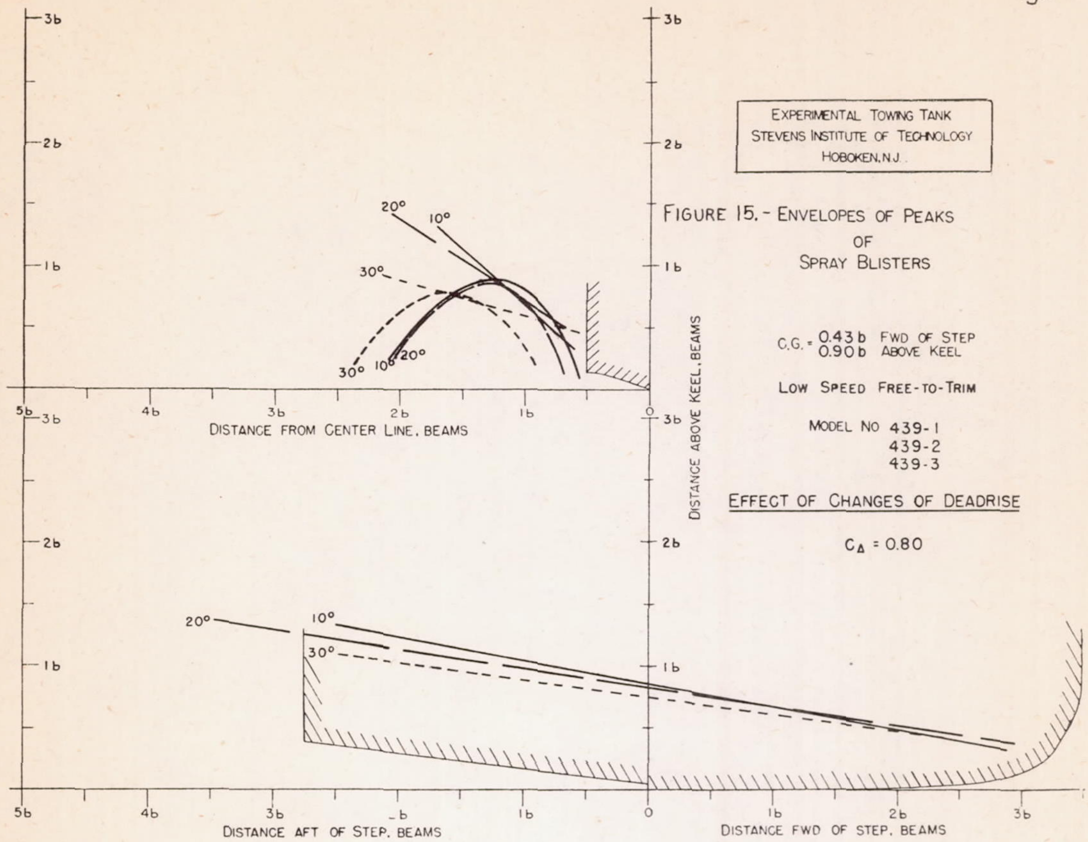


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FIGURE 15. - ENVELOPES OF PEAKS OF SPRAY BLISTERS

C.G. = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

LOW SPEED FREE-TO-TRIM

MODEL NO 439-1
439-2
439-3

EFFECT OF CHANGES OF DEADRISE

$C_\Delta$ = 0.80

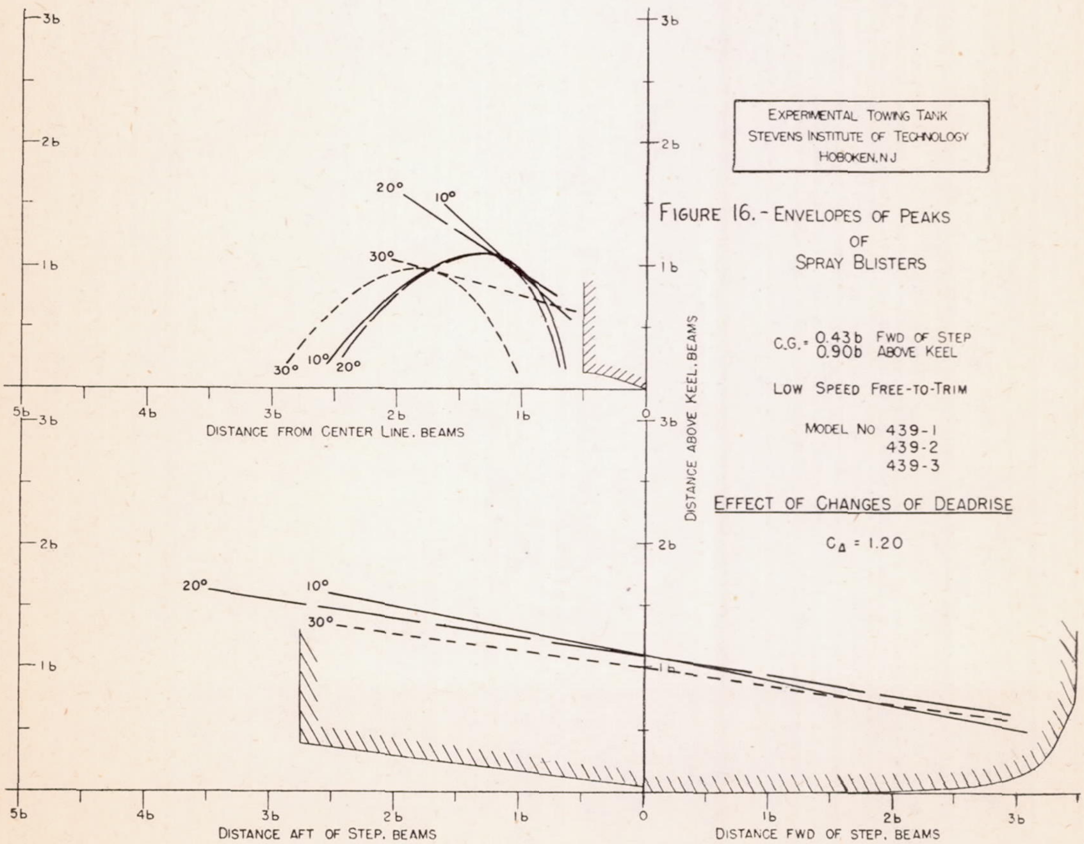


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FIGURE 16. - ENVELOPES OF PEAKS OF SPRAY BLISTERS

C.G. = 0.43 b FWD OF STEP
0.90b ABOVE KEEL

LOW SPEED FREE-TO-TRIM

MODEL NO 439-1
439-2
439-3

EFFECT OF CHANGES OF DEADRISE

$C_\Delta$ = 1.20

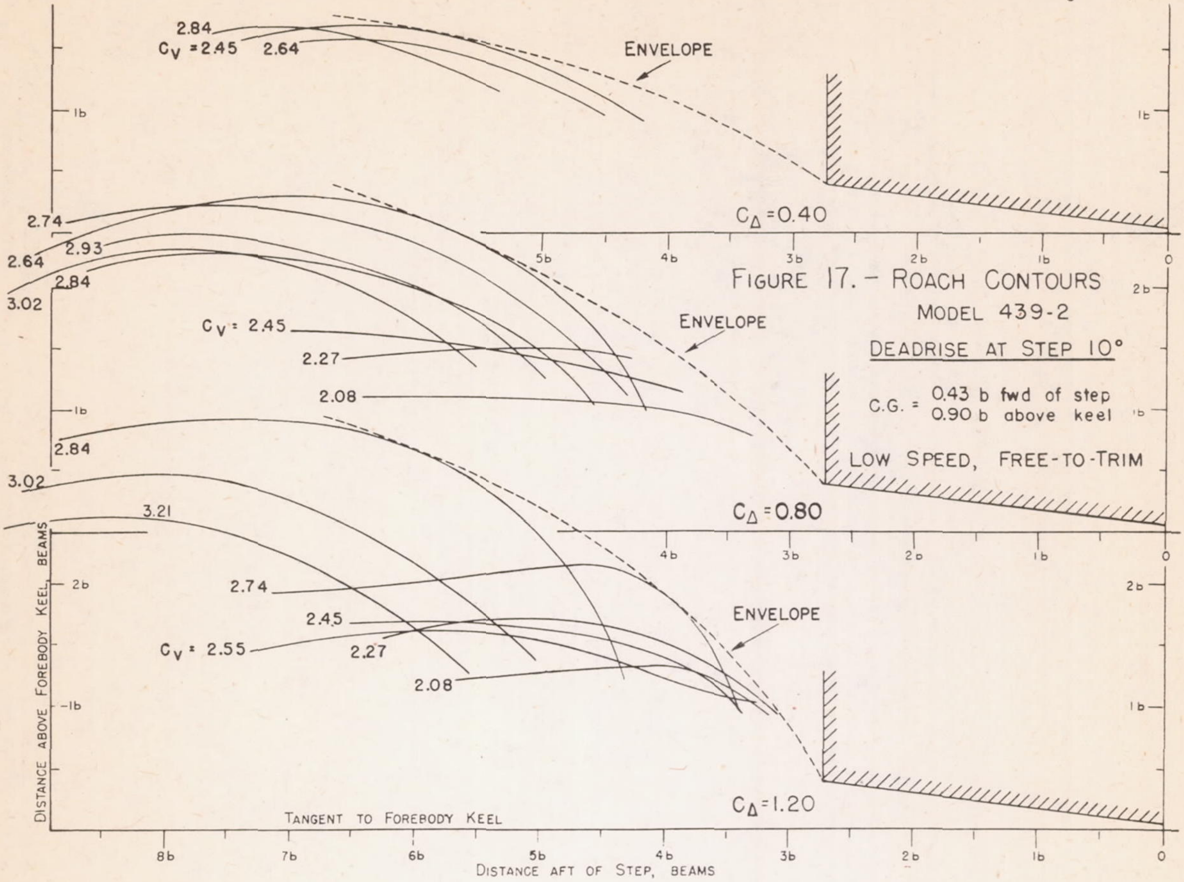


Figure 17. - Roach contours
Model 439-2
Deadrise at step 10°

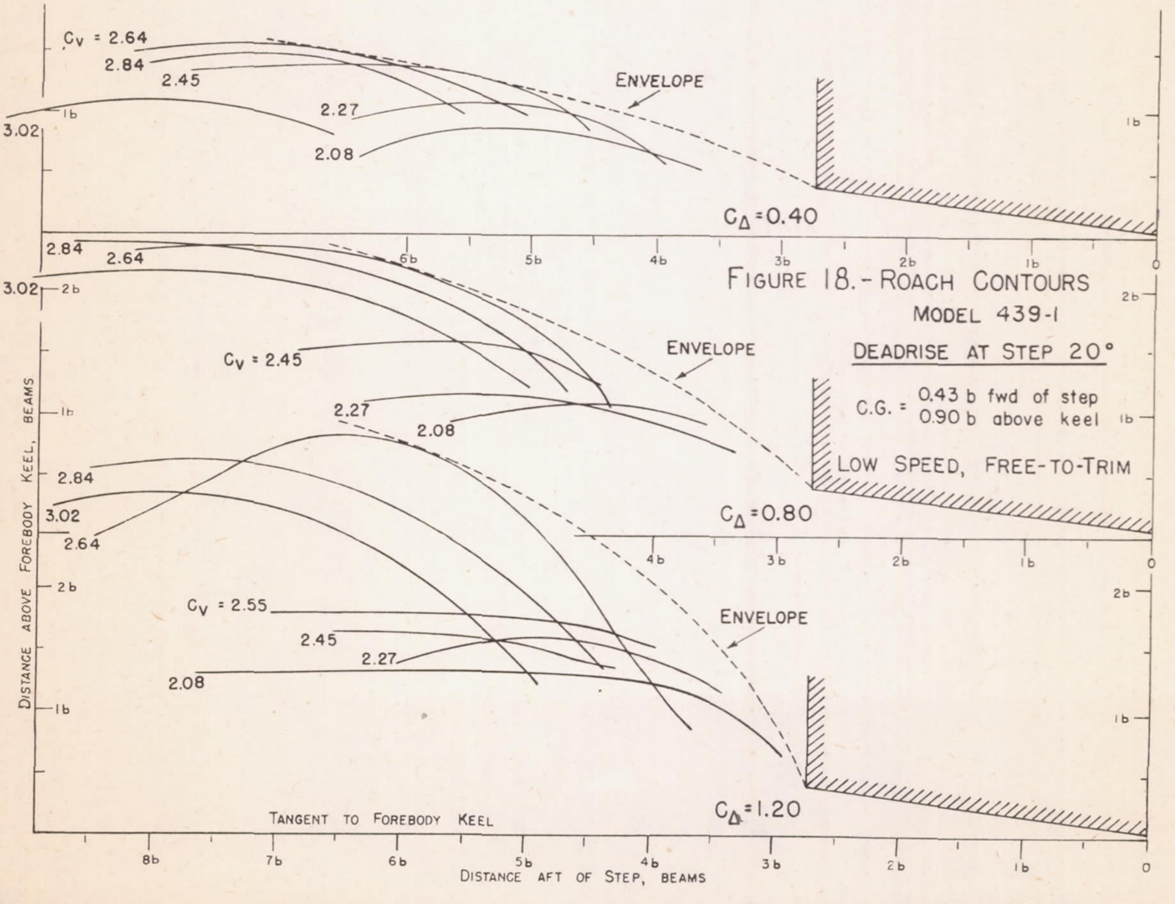


Figure 18. - Roach contours
Model 439-1
Deadrise at step 20°

W-69

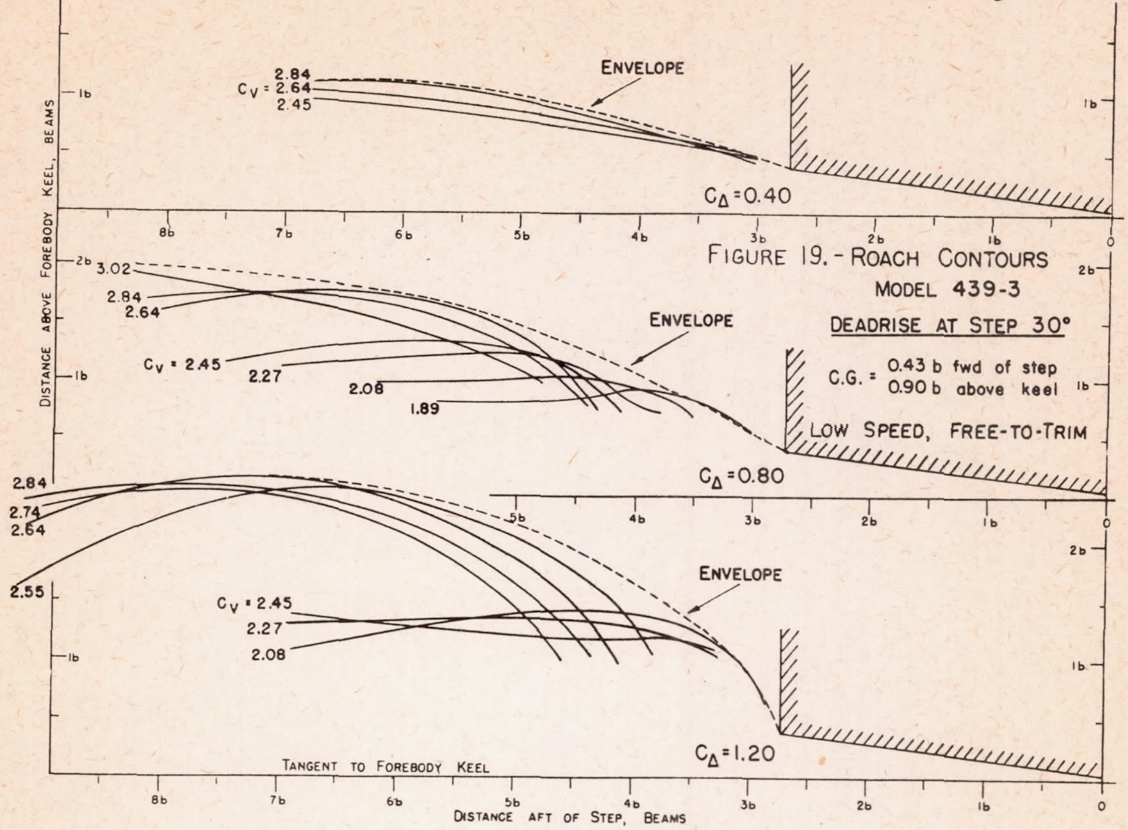


FIGURE 19. - ROACH CONTOURS
MODEL 439-3
DEADRISE AT STEP 30°
C.G. = 0.43 b fwd of step, 0.90 b above keel
LOW SPEED, FREE-TO-TRIM

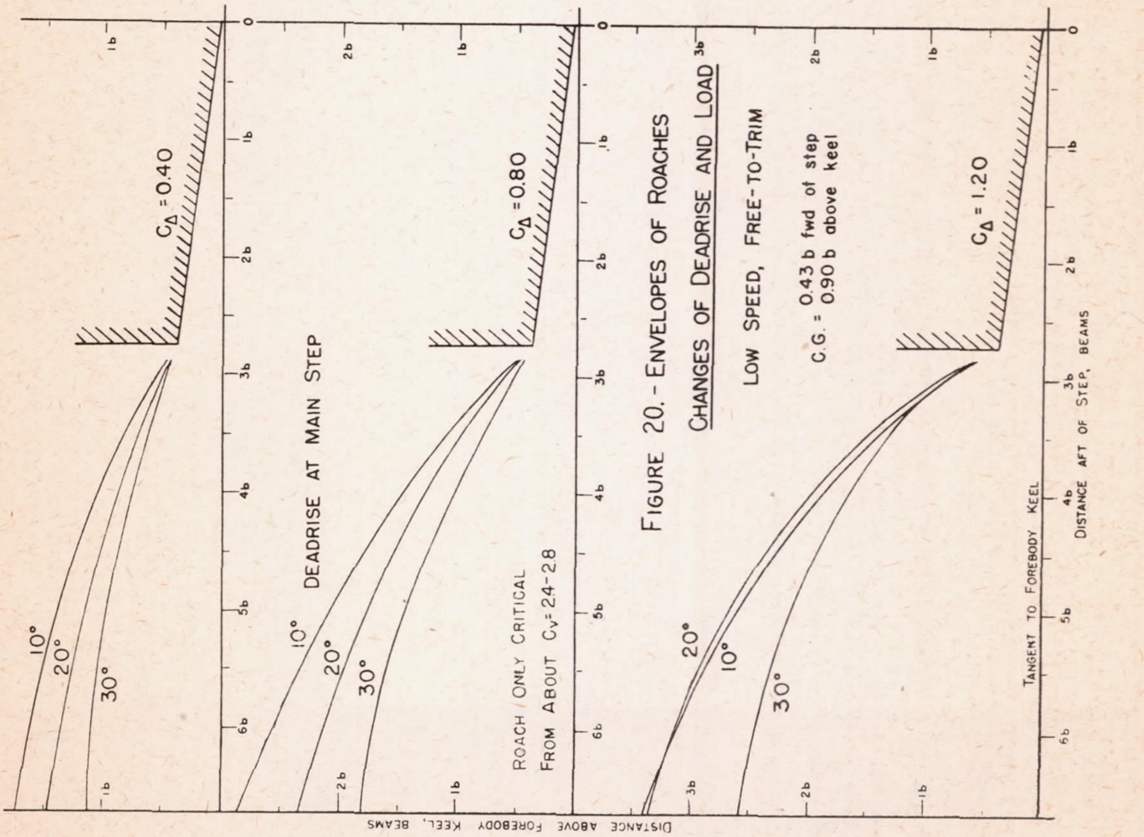


FIGURE 20. - ENVELOPES OF ROACHES
CHANGES OF DEADRISE AND LOAD
LOW SPEED, FREE-TO-TRIM
C.G. = 0.43 b fwd of step, 0.90 b above keel

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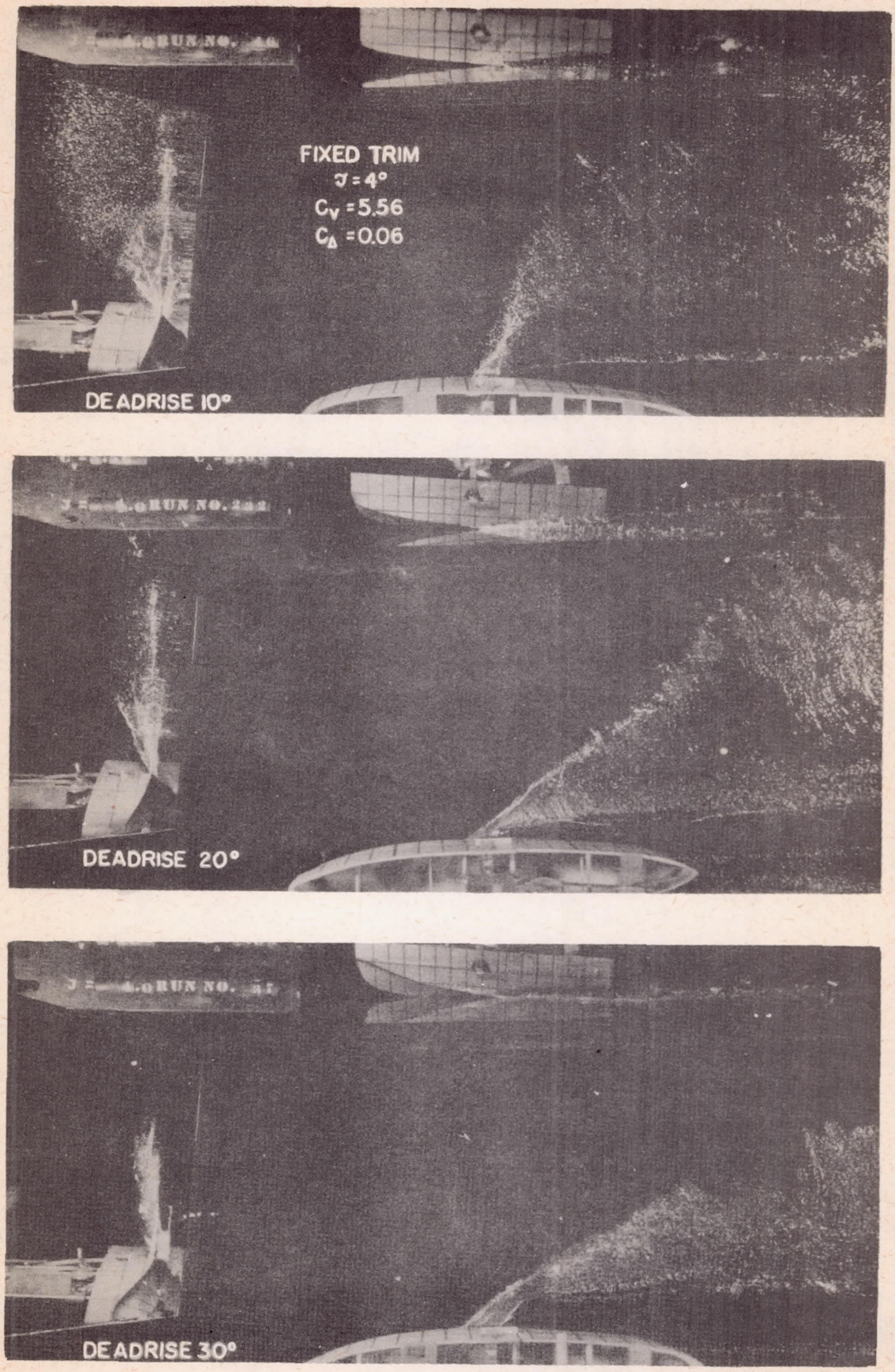


Figure 21

W-69

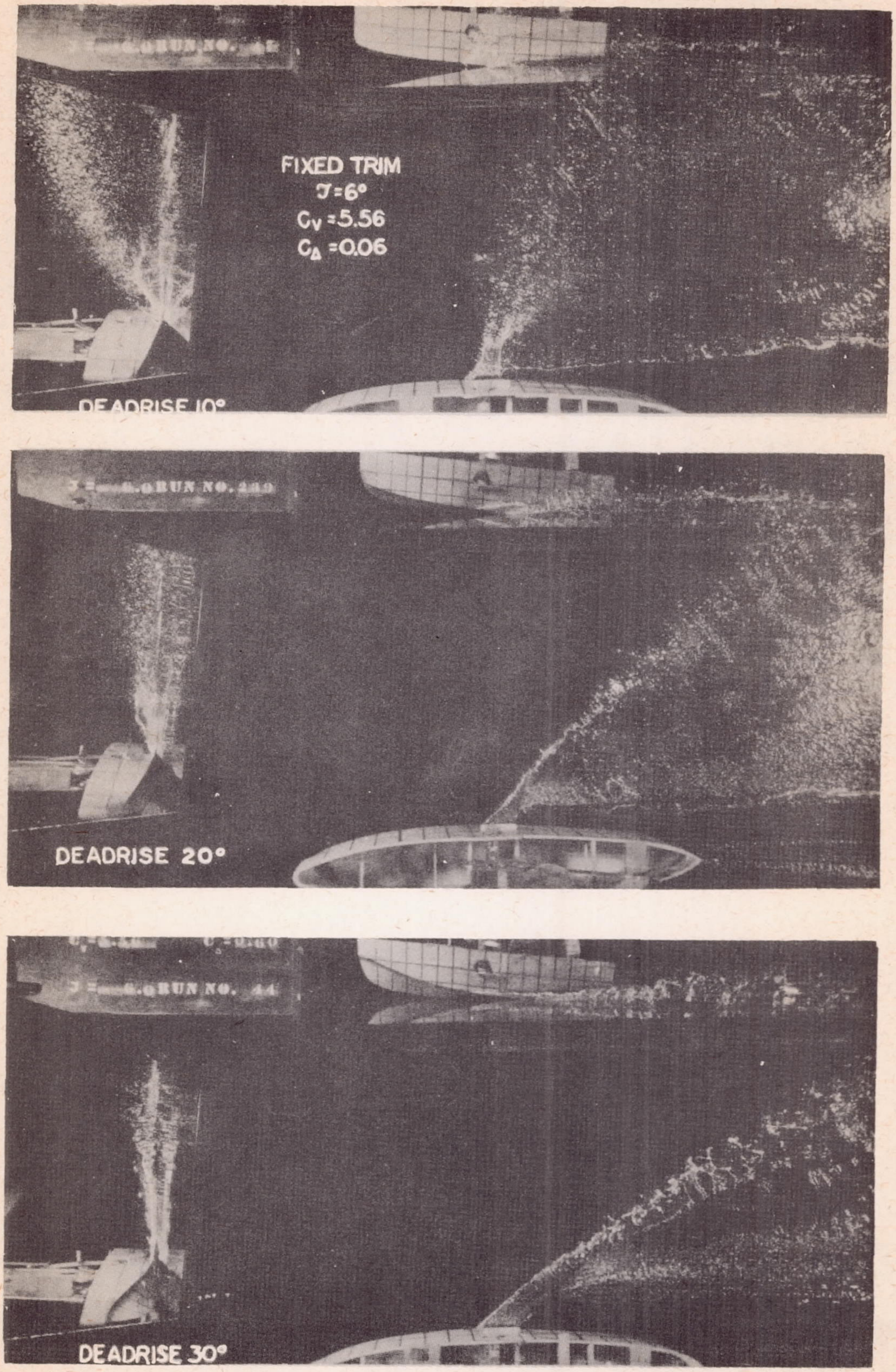


Figure 22

W-69

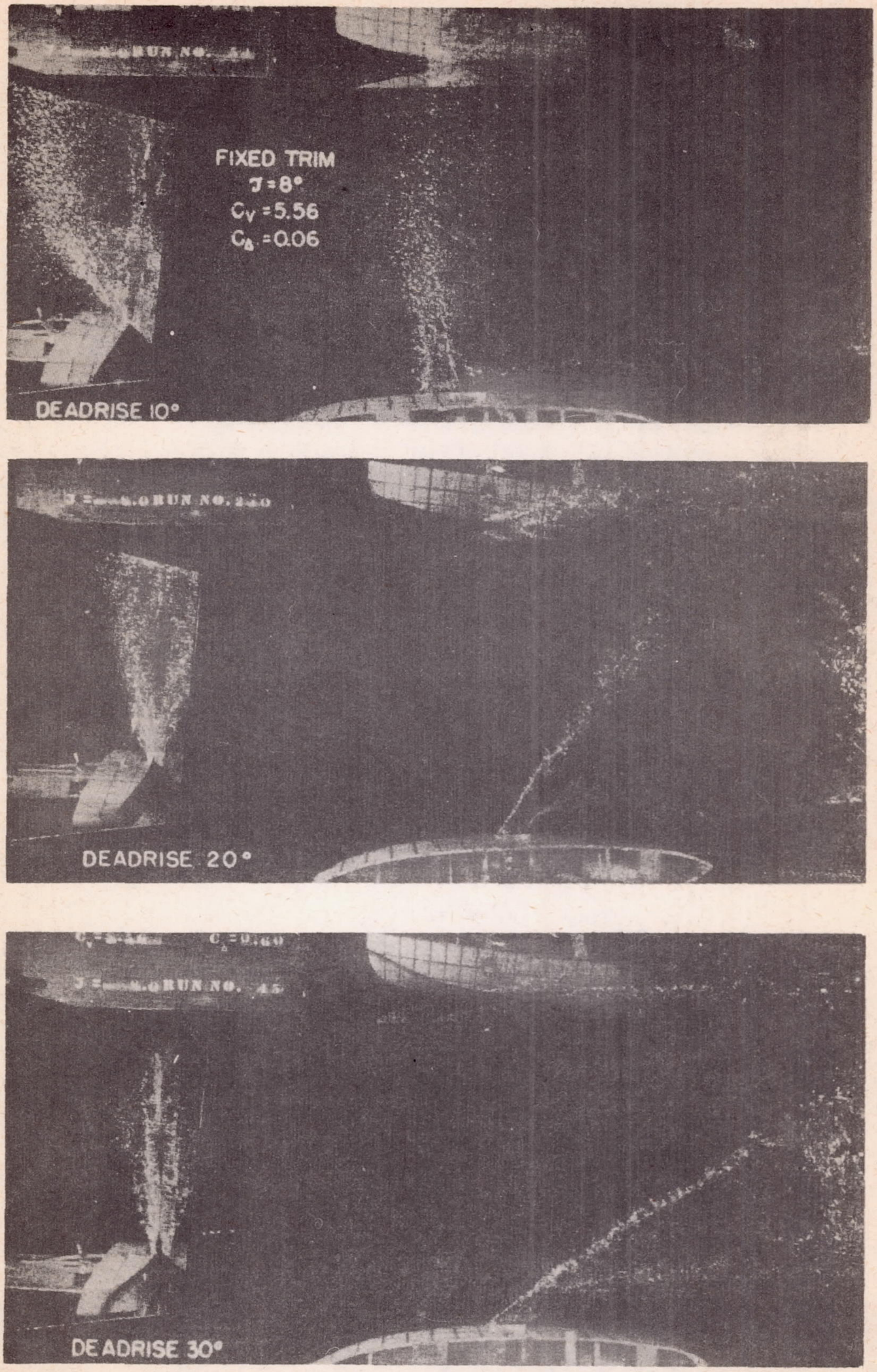


Figure 23

W-69

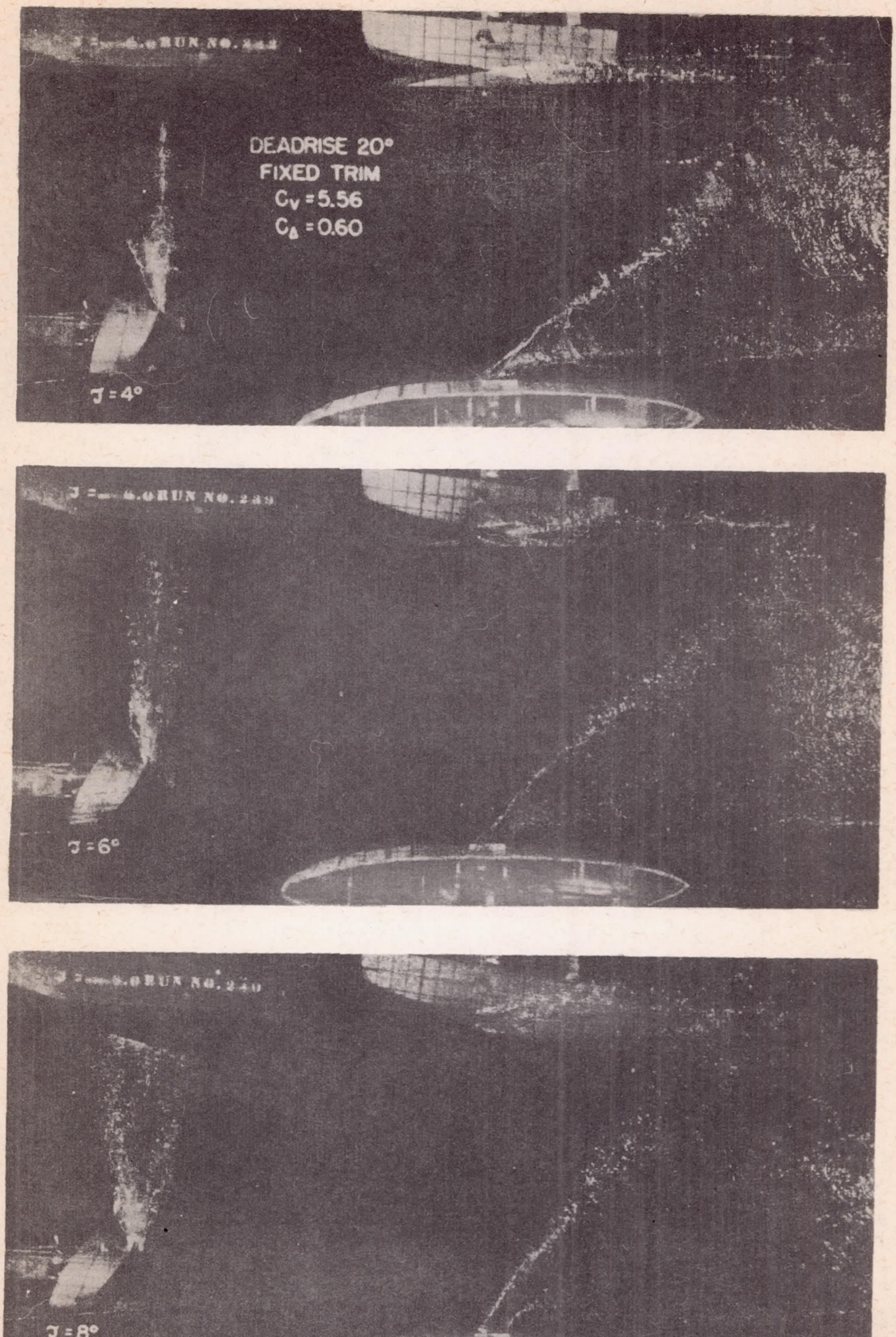


Figure 24

W-69

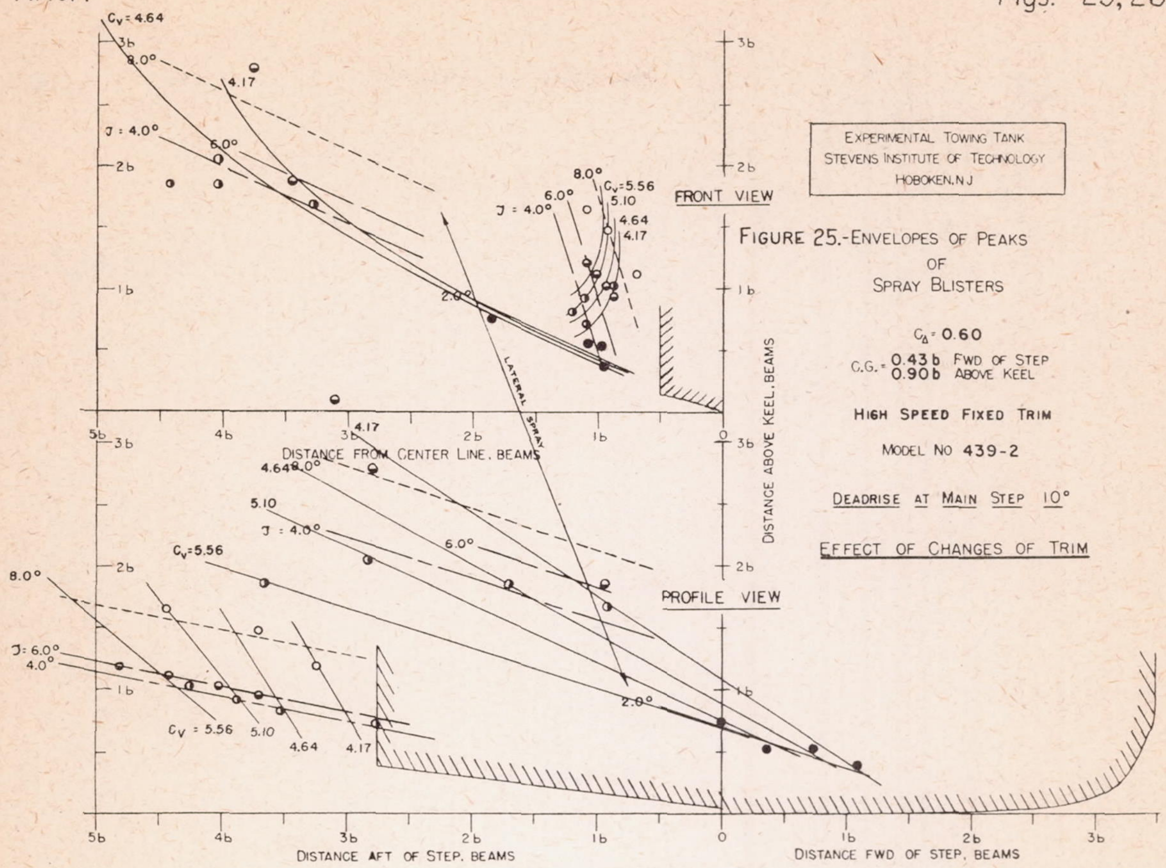


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FIGURE 25.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta$ = 0.60

C.G. = 0.43 b FWD OF STEP, 0.90 b ABOVE KEEL

HIGH SPEED FIXED TRIM

MODEL NO 439-2

DEADRISE AT MAIN STEP 10°

EFFECT OF CHANGES OF TRIM

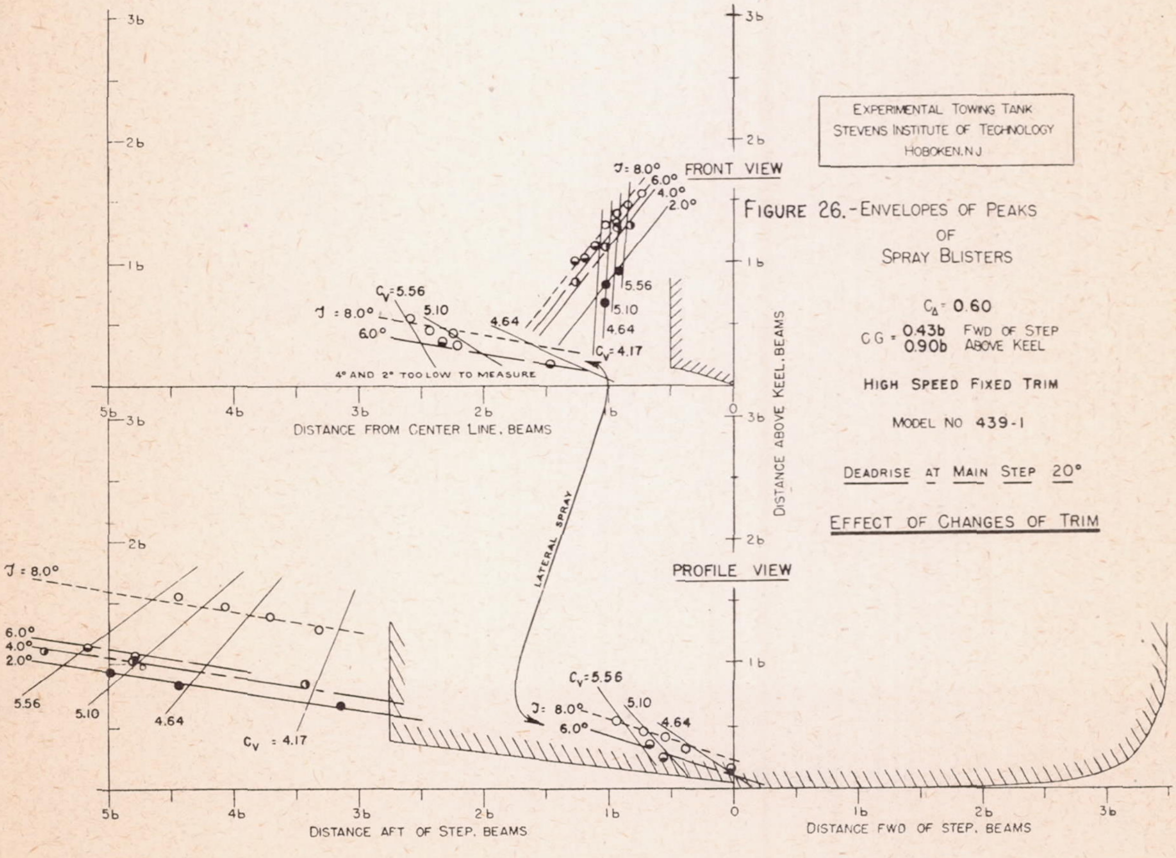


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FIGURE 26.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta$ = 0.60

C.G. = 0.43b FWD OF STEP, 0.90b ABOVE KEEL

HIGH SPEED FIXED TRIM

MODEL NO 439-1

DEADRISE AT MAIN STEP 20°

EFFECT OF CHANGES OF TRIM

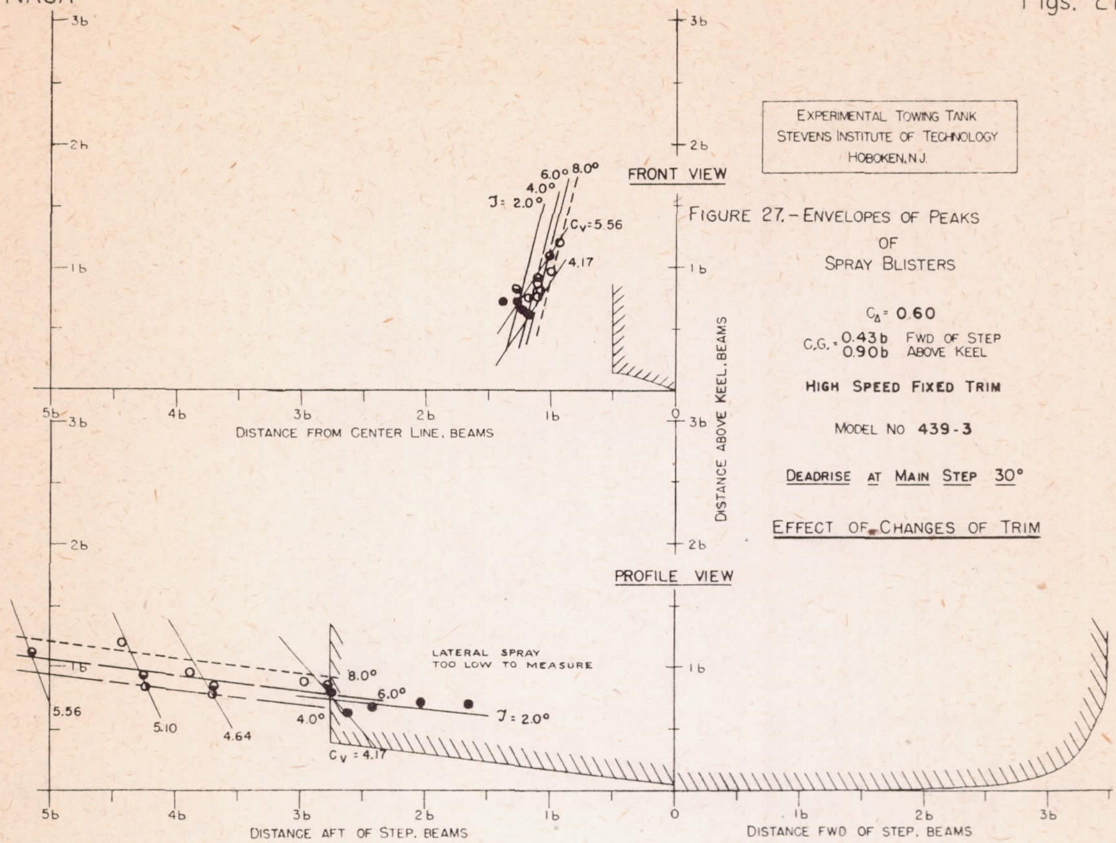


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FIGURE 27.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta = 0.60$

C.G. = 0.43b FWD OF STEP, 0.90b ABOVE KEEL

HIGH SPEED FIXED TRIM

MODEL NO 439-3

DEADRISE AT MAIN STEP 30°

EFFECT OF CHANGES OF TRIM

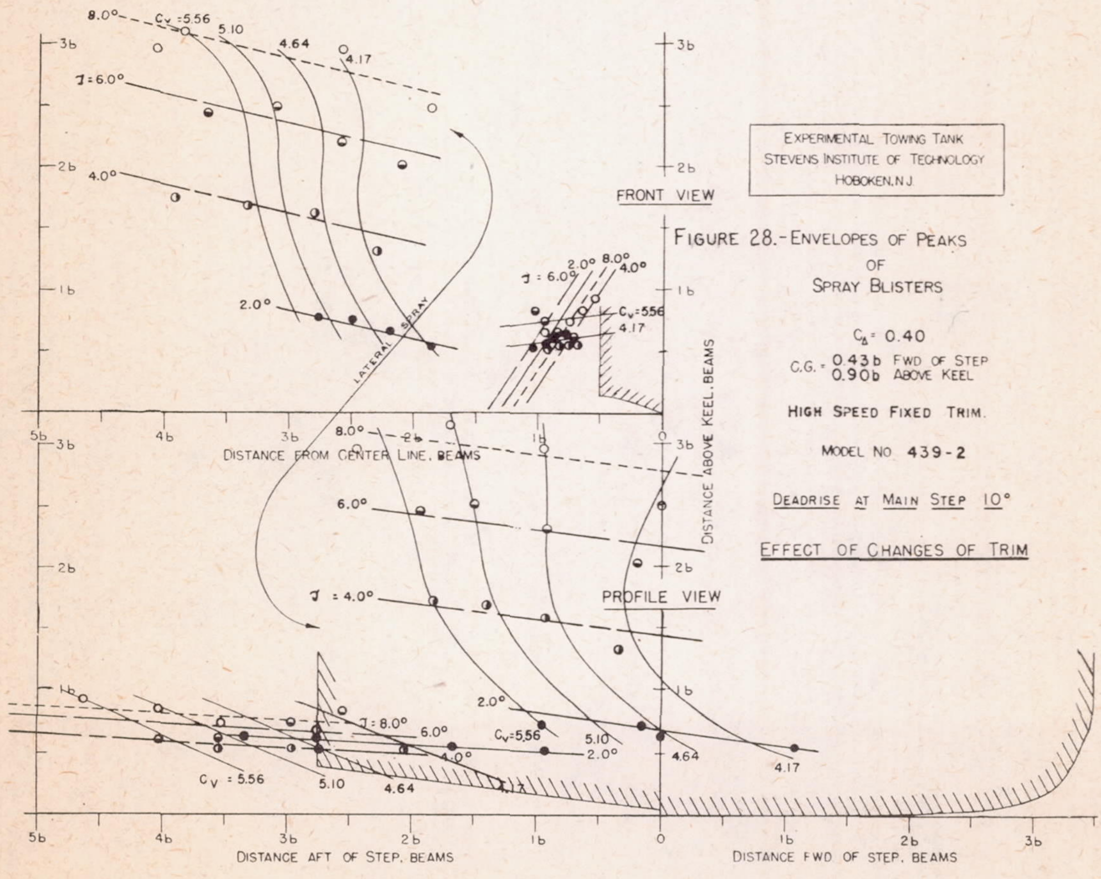


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FIGURE 28.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta = 0.40$

C.G. = 0.43b FWD OF STEP, 0.90b ABOVE KEEL

HIGH SPEED FIXED TRIM.

MODEL NO 439-2

DEADRISE AT MAIN STEP 10°

EFFECT OF CHANGES OF TRIM

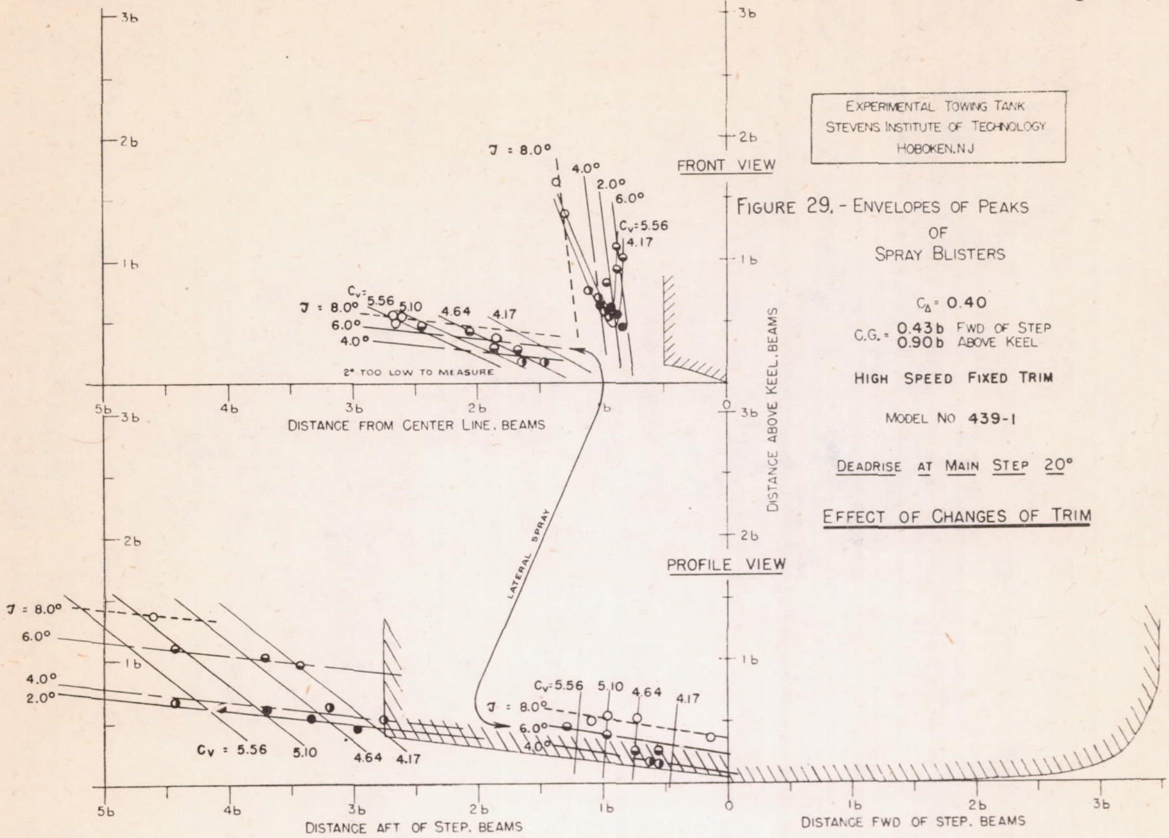


FIGURE 29. - ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta = 0.40$

C.G. = 0.43 b Fwd of Step, 0.90 b Above Keel

High Speed Fixed Trim

Model No 439-1

Deadrise at Main Step 20°

Effect of Changes of Trim

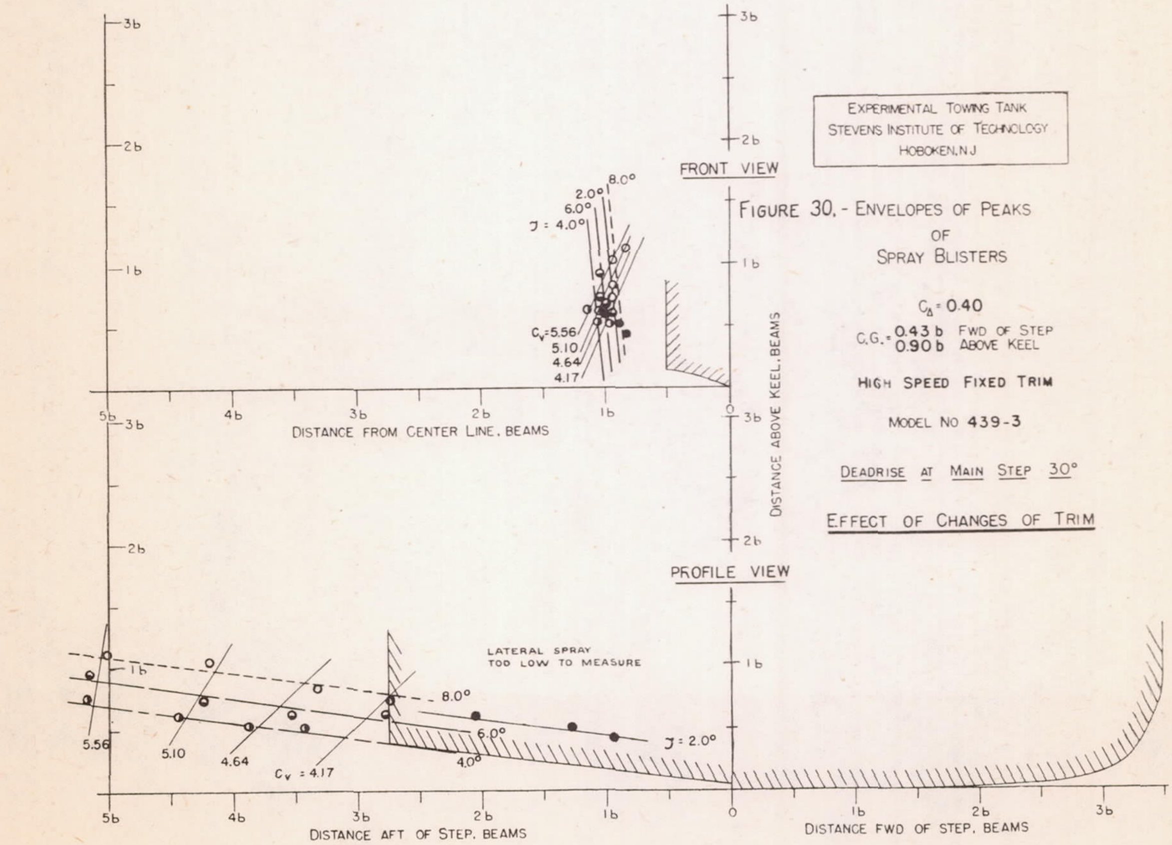


FIGURE 30. - ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta = 0.40$

C.G. = 0.43 b Fwd of Step, 0.90 b Above Keel

High Speed Fixed Trim

Model No 439-3

Deadrise at Main Step 30°

Effect of Changes of Trim

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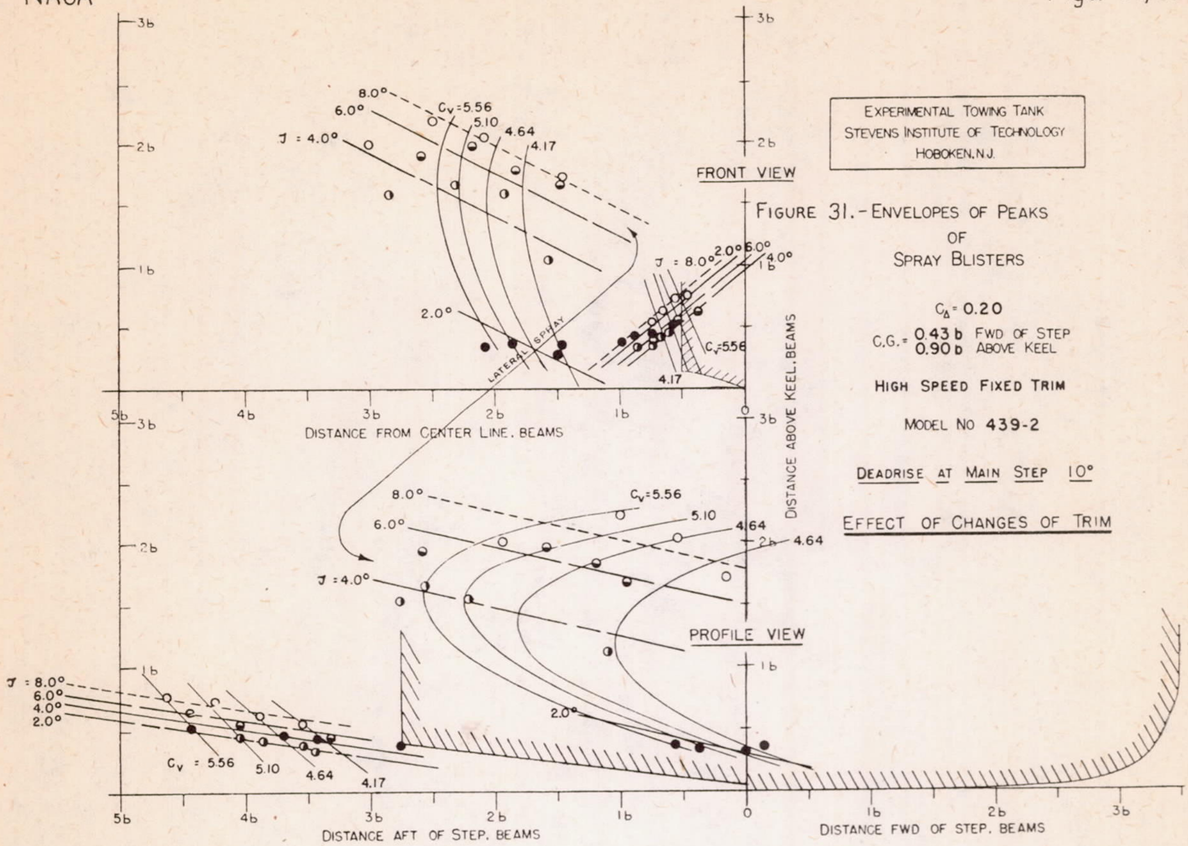


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FIGURE 31.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta$ = 0.20

C.G. = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

HIGH SPEED FIXED TRIM

MODEL NO 439-2

DEADRISE AT MAIN STEP 10°

EFFECT OF CHANGES OF TRIM

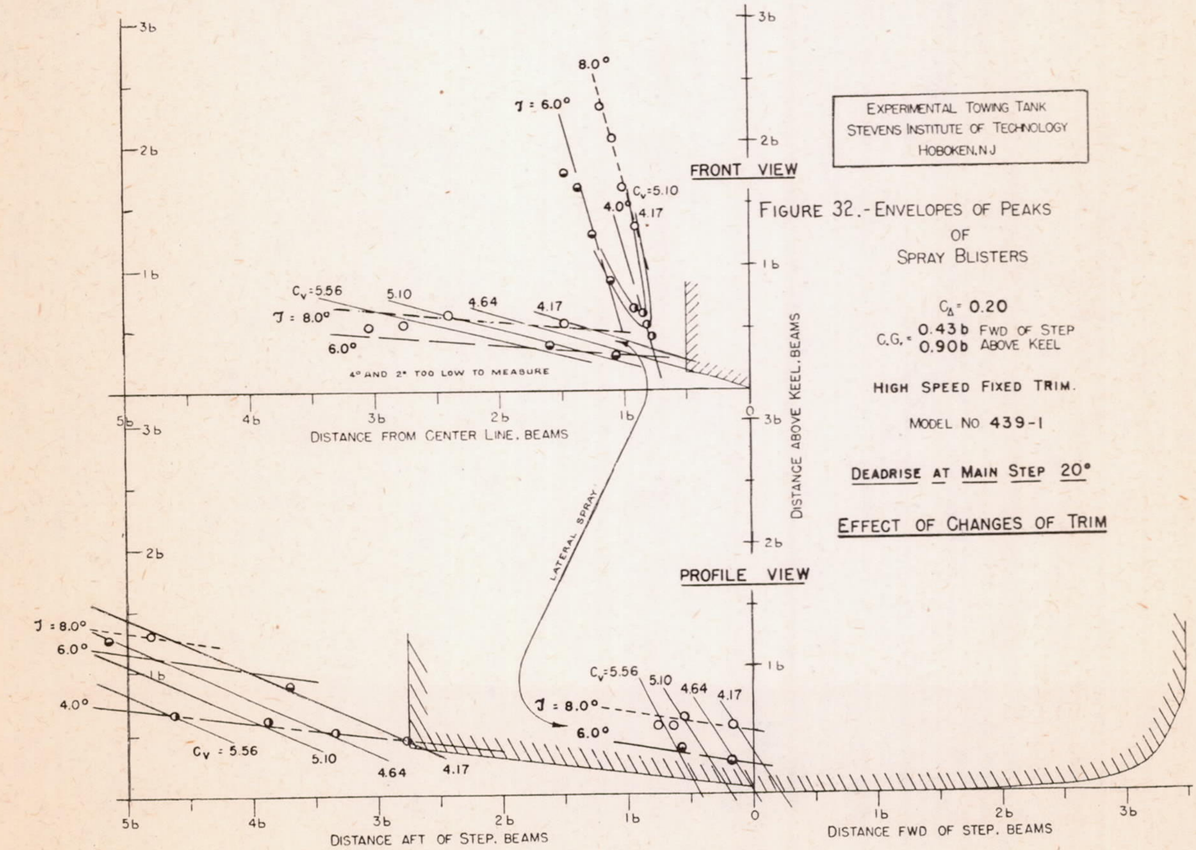


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FIGURE 32.- ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta$ = 0.20

C.G. = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

HIGH SPEED FIXED TRIM.

MODEL NO 439-1

DEADRISE AT MAIN STEP 20°

EFFECT OF CHANGES OF TRIM

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NACA

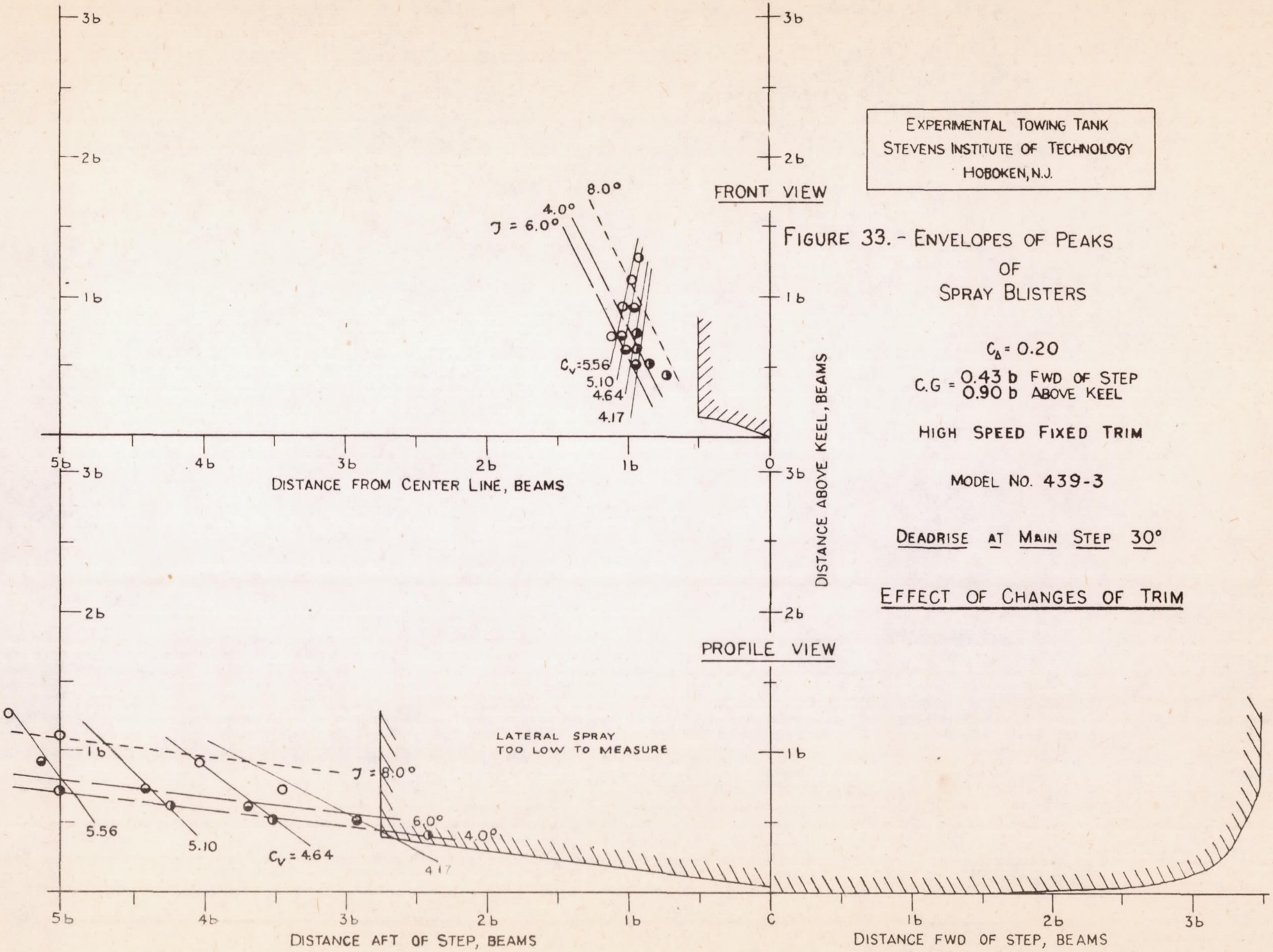


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FIGURE 33. - ENVELOPES OF PEAKS OF SPRAY BLISTERS

$C_\Delta$ = 0.20

C.G = 0.43 b FWD OF STEP
0.90 b ABOVE KEEL

HIGH SPEED FIXED TRIM

MODEL NO. 439-3

DEADRISE AT MAIN STEP 30°

EFFECT OF CHANGES OF TRIM

Fig. 33